KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF SCIENCE

FACULTY OF BIOSCIENCES

DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY

Use of Stearin and Olein as a Cocoa Butter Equivalent in Chocolate Making

BY JOANA KONADU ATTAFUAH JUNE 2019

USE OF STEARIN AND OLEIN AS A COCOA BUTTER EQUIVALENT IN CHOCOLATE MAKING

KNUST

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc. FOOD SCIENCE AND TECHNOLOGY) DEGREE

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JUNE 2019

DECLARATION

I hereby declare that I have undertaken the study reported herein under the supervision of Francis Alemawor (PhD) at the Food Science and Technology Department, KNUST-Kumasi as my own work towards the award of MSc. Food Science and Technology and that to the best of my knowledge, it contains no material previously published by another person except where due acknowledgment has been made in the text.

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ACKNOWLEDGEMENT

I thank the Almighty God for seeing me through the programme. I thank my Supervisor, Dr Francis Alemawor, and all lecturers at the Food Science and Technology Department of KNUST. I'm grateful to the lab assistants also. Much appreciation goes to Dr Isaac Ofosu and Dr (Mrs) Gloria Ankaar-Brewoo all of Food Science Department for their immeasurable support.

An outstanding appreciation goes to my parents, siblings, friends, course mates (MSc Food Science and Technology 2017/18), Benjamin Nyarko and Cyril Roland Asiedu for their support and words of encouragement.

ABSTRACT

Cocoa butter a salient ingredient in the chocolate recipe, imparts desirable properties to the chocolate product unlike other vegetable oils. The unsteady supply and hike in price made chocolate producers seek alternatives to cocoa butter. The EU passed a legislation that allows the use of 5% of cocoa butter equivalent on product base in chocolate production. This study was to formulate cocoa butter equivalent from shea stearin and palm olein and to evaluate the magnitude of sensorial difference and preference of chocolate made with the cocoa butter equivalent. Response Surface Method was used to obtain various ratios of shea stearin and palm olein to use in chocolate formulation. Specific gravity and Refractive indices of the various oils as well as their peroxide value (PV) and free fatty acid (FFA) value were analysed. PV and FFA values of all oils used in the chocolate formulation were within the acceptable limits of below 10meq for PV and not more than 1.75% for FFA. Panellists observed significant difference between chocolates made with 5% CBEs and that made with CB only. However, there was no significant difference in panellists acceptance/preference of chocolates made with either CB or CBEs. This may imply that CBE formulated could develop consumer acceptable chocolate.

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LIST OF ABBSREVIATIONS

CBAs – Cocoa Butter Alternative

CBEs – Cocoa Butter Equivalents

CBIs – Cocoa Butter Improvers

CBRs – Cocoa Butter Replacers

CBSs – Cocoa Butter Substitutes

CRIG – Cocoa Research Institute of Ghana

ICCO – International Cocoa Organisation

ISSER – Institute of Statistical, Social and Economic Research

MT – Metric Tonnes

NRCS – Natural Resource Conservation Services

PMF – Palm Mid-Fraction

RSM – Response Surface Method

USDA – United States Department of Agriculture

WCF - World Cocoa Foundation

%m/m – mass percent concentration

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Originating from the tropical rainforest is a legendary tree known as "food of the gods"; *Theobroma* which is subsequently used to produce a drink the early Maya people referred to as the "drink of the gods". The drink of the gods is a chocolate drink the early people made by grinding dried cocoa beans, dissolving it in water and adding cinnamon and pepper. This chocolate drink was bitter and Verna (2013) asserted that this drink was valued more for its revitalizing and stimulating effect than its taste. Thus, the food of the gods was beans from the cocoa pod. The cocoa tree requires specific climatic conditions to grow hence its domestication has been restricted to such areas. Three countries of which Ghana is included are noted the leading producers of cocoa (Statista, 2017).

The cocoa tree produces cabossides (cocoa pods) which holds the cocoa beans. The cocoa tree produces no waste, in that every part of the pod it bears is useful. The husk is incinerated to produce potash, a fertilizer, the cocoa beans are edible due to the sweet pulp around it and same can be used in the production of juices and marmalades, then from grinding of the dried cocoa beans, cocoa liquor is produced, heating and pressing of the liquor results in cocoa powder and cocoa butter (Amoa-Awua et al., 2007; ICCO, 2003; CRIG, 2015). It is from the products (cocoa butter and cocoa liquor) of the pulverized dried cocoa beans with additional ingredients that modern day chocolate is made.

Verna (2013) outlined the transitioning made from the Aztecs bitter "drink of the gods" to the modern-day sweet chocolate. He expands on how the Spaniards made the drink hotter and how the Europeans produced a milder version of the drink; hot and sweet till 1847 when Fry made solid chocolate bars.

Though the cabosside has diverse uses, its main money earner is the cocoa beans, specifically products obtained from the beans. Cocoa liquor, cocoa butter and cocoa powder are primary products of cocoa and do not fetch as much money as the secondary products (high-value added products) such as chocolate, other confectioneries, beverages and cocoa based cosmetics (Essegbey and Ofori-Gyamfi, 2012).

However, Ghana as the second largest cocoa producing country, exports more of the primary products than the secondary and tertiary products of cocoa. The lack of investment in the production of high value-added products causes the country not to make as much money as they could from the cocoa. The chocolate industry is estimated to be valued at US$ 110 billion of which Ghana and Cote d'Ivoire jointly hold a share of US$ 5million (PinnamangTutu and Armah, 2011; Eduku, 2017; Sulaiman and Boachie-Danquah, 2017).

Aside Ghana making less due to minimal production of high-value added products, local patronage and consumption of cocoa and its products (both primary and secondary) is not encouraging (Essegbey and Ofori-Gyamfi, 2012). Findings from a research conducted by ISSER (2011) indicated that Ghana could make more from cocoa cultivation aside exporting if a greater percentage of it is consumed locally. However, a study on consumer attitude towards foreign and domestic chocolate indicated that the average Ghanaian does not have the purchasing power to make consumption of chocolate a regular routine (Kissiedu, 2012).

Local consumers therefore relegate the consumption of chocolate to festive seasons (Christmas, Eid and Chocolate day) and gift offerings to friends.

Across the globe, a major contributing factor to the cost of chocolate is the cost and related issues of its main ingredient; cocoa butter. As a major ingredient in confectionery production, manufacturers in the chocolate industries have cited unsteady cocoa butter supply and hike in cocoa butter prices as their reasons for seeking alternatives to cocoa butter. This resulted in the pursuance of CBAs which usually comprise blends of vegetable fats (Wang et al., 2006; Depoortere, 2011; ICCO, 2014). There are three groups under the CBAs; CBE, CBR and CBS, each offering a varied proportion at which they can be blended with cocoa butter. Amongst the three groups, CBE is the most important (Talbot, 2009).

Despite being a threat to the cocoa butter economy, these CBEs have been allowed in chocolates by the EU at a 5% level on product base and some leading chocolate producers, Hershey and Mondelēz International (subsidiary; Cardbury) are already into chocolate production with CBAs (EU Regulation, 2003; Jahurul *et al.*, 2012; Hussain *et al.*, 2018).

Based on the 2003 EU Regulation and food standards set by FAO/WHO (2003), only six tropical vegetable fats can be used as CBEs in chocolate. Usually, CBEs are prepared from blends of fractionated shea and hard palm mid-fraction. Of these six vegetable fats, shea butter and palm oil are native and abundant in Ghana.

1.2 Problem Statement and Justification

The cultivation of cocoa in Ghana was previously for exportation as a foreign exchange earner hence little value was added to the cocoa beans. Ghanaians developed the habit of rather selling cocoa beans to gain money than consuming the beans and its products for satisfaction (Kissiedu, 2012). ISSER (2011) indicated that Ghana could make more from cocoa cultivation aside exporting if a greater percentage of it is consumed locally. The average Ghanaian mentions high price of cocoa products as the reason for not purchasing them. The high price of these products is influenced by the hike in price of cocoa butter.

Due to the unsteady supply and subsequent hike in price of cocoa butter, manufacturers in the chocolate industry are seeking alternatives to cocoa butter. The CBE industry promises to be lucrative as the world's leading producers of chocolate are allowing percentages of CBEs in their chocolates and other confectioneries (Jahurul *et al.*, 2012). The CBEs may reduce cost but not affect sensorial quality of chocolate and hence be affordable to the average Ghanaian.

A Chinese proverb goes as, “when the wind of change blows, some people build walls, others build windmills”.

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1.3 Objectives

The purpose of the study is to formulate CBE comparable to cocoa butter and produce chocolate acceptable to local consumers from the CBE formulated.

The specific objectives of this study are outlined below:

1. To formulate suitable cocoa butter equivalents from shea stearin and palm olein
2. To evaluate the magnitude of sensorial difference and preference of chocolate made with the cocoa butter equivalent.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cocoa History

Theobroma cacao is the scientific name of what is commonly called cocoa in English or cacao in French, Spanish and Italy. The generic name, *Theobroma* translates to mean “food of the gods". It originated from the combination of two Latin words; 'theos' which means god and 'broma' which means food (Orwa *et al*., 2009). Cacao on the other hand is from Nahuatl (Aztec language) words *'xocolatl'*, also a combination of words; '*xococ*' meaning bitter and '*atl*' meaning water (Afoakwa, 2010). Generally, the word cacao is used when referring to the tree whereas, cocoa is used to describe the products obtained from the dried fermented seeds (Bartley, 2005). The table below shows the taxonomy of cocoa.

Table 2.1 Taxonomy of cocoa

Rank	Scientific Name	Common name
Kingdom	Plantae	Plants
Subkingdom	Tracheobionta	Vascular plants
Super division	Spermatophyta	Seed plants
Division	Magnoliophyta	Flowering plants
Class	Magnoliopsida	Dicotyledon
Subclass	Dilleniidae	-
Order	Malvales	-
Family	Sterculiaceae	Cacao family
Genus	*Theobroma* L.	theobroma
Species	Theobroma cacao L.	cacao

Source: USDA, NRCS (2018)

Bayer and Kubitzki (2003) classified *Theobroma cacao* as a member of the family Malvaceae.

There are twenty-two (22) species of the *Theobroma* genus of which *Theobroma cacao* is the most widely known. It is believed to have originated from tropical South America; the eastern section of the Andes (International Cocoa Organisation, 2013) and has proved to be an essential tropical rainforest tree since its domestication and cultivation. *Theobroma cacao* is native to Brazil, Mexico and the United States of America (Orwa *et al*., 2009). According to Edoh and

Ngo-Samnick (2014), there are three regions currently serving as the main cocoa producing areas. They are the Gulf of Guinea (with countries such as Cote d'Ivoire, Ghana, Nigeria and Cameroon), South Asia and Oceania (example, Indonesia, Malaysia, Papau New Guinea) and South and Central America (examples of producing countries are, Brazil, Peru, Ecuador). Of these regions, the countries known as leading producers of cocoa in ascending order of produce are Cote d'Ivoire, Ghana and Indonesia with production rates of 2.01 million MT, 0.95 million MT and 0.29 million MT respectively in the year 2016/17 (Statista, 2017).

2.1.1 History of Cocoa in Ghana

Bartley (2005) reports the cultivation of cacao in Africa as starting with the Portuguese establishing Amelonado cacao on an island in Central Africa; Príncipe in 1822. After about three decades of its commercial cultivation there, the crop was introduced to the mainland São Tomé where for some period in the 20th Century the colony was the largest producer of cacao. Spaniards who had by then taken up the Fernando Pó island close to São Tomé, also introduced the cacao to Fernando Pó (now Bioko), Equatorial Guinea. From there, the crop was introduced continually into West Africa.

It is believed that Tetteh Quarshie after a visit to Fernando Po in 1879 introduced the cacao beans to Ghana. Another school of thought has it that Basel Missionaries resident at Akropong introduced the crop to the country (Wanner, 1962; Legg, 1972; Adzaho, 2007). Current breeds grown in the country are hence crosses between the cultivars earlier introduced.

2.2 Cocoa varieties

The International Cocoa Organisations (2013) mentions *Criollo, Forastero* and *Trinitario* as the three (3) principal varieties of cocoa tree. The Criollo and Trinitario cultivars are known to produce "fine or flavour" cocoa beans and are mostly found growing in Central and South America. Forastero which is also grown chiefly in West Africa and Brazil is known for its "bulk" cocoa beans.

Criollo and Forastero are named the major cocoa population whereas Trinitaro is a hybrid between the two (Bartley, 2005; ICCO, 2013). In demonstrating their differences, the various cultivars are dissimilar in appearance of pod and cocoa beans, have unique flavour characteristics and is resistance to pests and diseases (Afoakwa et al., 2008).

2.2.1 Criollo

Criollo is a Spanish word meaning "native" or "first grown". The cacao variety Criollo was so named to affirm its position as the one cultivated first outside the range of the cacao indigenous species. The name thus distinguishes it from the other species (Bartley, 2005).

Generally, cocoa beans from the Criollo variety is described as "fine or flavour" cocoa beans. Until the eighteenth (18th) century, Criollo trees dominated the market but due to difficulty in its cultivation outside Mesoamerica, its native region, it is considered a scarce commodity on the modern market as only a few "pure" criollo remains (International Cocoa Organisation, 2013). This variety is dominant in Indonesia, Central and South America.

The skin of the Criollo pod is crinkly and pointed, it's red when mature and green when immature. They are comparatively softer with bean appearing as either white, pale purple or ivory in colour (Schwan and Fleet, 2014).

2.2.2 Forastero

Forastero in Spanish means "of the forest" or "foreign" which implies that it is not native to the region or was not part of the initially cultivated ones. This variety has a harder pod, and this makes the pod breaking process quite laborious (ICCO, 2013).

Wollgast and Anklam (2000) mentioned that the anthocyanin, a water-soluble pigment found in the cotyledon of the Forastero cocoa beans makes the beans appear purple or violet. However, Schwan and Fleet (2014) described the same cocoa beans as dark brown. The anthocyanin pigment is pH dependent hence the beans changes colour with fluctuations in pH. The Forastero trees are regarded as disease and pests resistant and produce flat beans (Bartley, 2005; Lima *et al.*, 2011).

2.2.3 Trinitario

The Trinitario population is believed to have naturally occurred in Trinidad by hybridization between remnant Criollo and the Forastero germplasm that was introduced from Venezuela in the middle of the 18th century (Cheesman 1944; Bartley 2005).

As hybrids, the Trinitario variety of cocoa bears characteristics of both Forastero and Criollo. They have pods harder than the Criollo with variable colour and their beans are of variable colour with a rare occurrence of a white bean. With respect to Trinitario's susceptibility to pests and diseases, it is said to be intermediary between the Criollo and Forastero (Fowler, 1999; Bartley, 2005; Kongor *et al.*, 2016).

2.2.4 Other varieties

Clement et al. (2010) categorises Nacional and Amelonado as "traditional cultivars" where Nacional and Criollo is classified as of Western Amazonia origin whilst Amelonado and French Guiana are of Eastern Amazonia origin.

Amelonado is Spanish for melon shaped and the shape of the pod earned this variety that name. This variety replaces completely or is hybridised with the Criollo variety because it is better adapted than the Criollo which does not thrive outside its native region. The Amelonado variety has thus spread wider than the Criollo (Zhang and Motilal, 2016).

2.3 Cocoa Farming

2.3.1 Climate and Environmental Requirement

The climatic conditions inherent in a place influence the type of biome (that is, a group of plant and animal life) resident therein. Climatic conditions are specific to a location and it is noted over a period. Two principal factors used in climatological analysis are temperature and rainfall (Balasubramanian, 2013).

The Köppen Climate Classification System centred on the monthly and annual averages of temperature and rainfall to characterise five (5) major climate groups. Designated by alphabets, they are; **A** - Moist Tropical Climates (Tropical), **B** - Dry Climates (Dry), **C** - In Humid Middle Latitude Climates (Temperate), **D** - Continental Climates (Continental), **E** - Cold Climates (Polar). Each of these groups have sub groups that form other climatic types (Chen and Chen, 2013).

The countries and locations noted as areas of origin of cocoa fall in the Tropical climate zone as this zone lies within areas from the equator to the Tropic of Capricorn southward and from the equator to the Tropic of Cancer northward. This zone is characterised by an average temperature range of 18 °C – 35 °C (64.4 °F – 95.2 °F), an annual rainfall of 60 – 100 inches (1524 – 2540 mm) and humidity of 77 % - 88 % (Balasubramanian, 2013).

The cocoa tree native to such conditions does well when moved into similar conditions. Thus, cocoa grows well in soils with good aeration and drainage with a pH range of 5.0 – 7.0 and rich humus covering the topsoil (Orwa *et al*., 2009). Adzaho (2007) asserted that cocoa trees flourish in areas where dry season does not exceed three (3) months and there is a mean monthly rainfall of 100 mm. He added that the minimum temperature required is between 18 °C - 21 °C with the maximum being 30 °C – 32 °C (Mossu, 1992; Adzaho, 2007).

Countries falling within this classification include Ivory Coast, Ghana, Malaysia and Brazil.

2.3.2 Cultivation

Generally, cocoa is propagated from seeds, where the seedlings are prepared on a nursery close to the actual farm for the cocoa planting. However, vegetative propagation of cutting or budding or grafting or marcotting can also be used in cocoa propagation (Zhang and Motilal, 2016). Wood and Lass (2008) observed that the vegetative propagation of budding or grafting or cutting is extensively practiced in Asia and Latin America.

For every acre of farming land, the average density of cocoa trees is set to a range of 2500 - 3000 trees (that is, 1000 – 1200 trees ha^{-1}) and a minimum of 600 trees ha^{-1}. At the early stages of its growth, the cocoa trees are delicate. Hence, to prevent the effects of strong winds during such period, crops such as plantain is used for intercropping on the farm. In Ecuador, Jamaica and West Africa, annual food crops such as yam, cocoyam and maize are intercropped on the cocoa farm to provide shade for the growing cocoa tree (Afoakwa, 2010). Asare and David (2011) emphasised that crops such as plantain and cassava may be planted 3 months to a year prior to the planting of the cocoa trees. This they noted will provide shade for the cocoa seedling and protect its early stages from harsh weather conditions.

As the cocoa tree grows, it is pruned to a height of 3 - 4 m to improve the tree canopy and ultimately provide ease in harvesting. Pruning encourages a succession of activities on the tree;

photosynthetic activity is improved, flower pollination is enhanced, new leaves are formed, and pod growth is encouraged. Again, dead branches and new branches growing upward out of the trunk (chupons) are removed. Generally, pruning controls crop diseases and insect attack. Decomposition of pruned parts on the farm is not encouraged (Wood and Lass, 2008) as it may encourage the retention of the pests on the farm.

Fertilizers when applied to the crop are believed to extend the productive life of the cocoa trees. Moriarty *et al*. (2014) observed that approximately fertilizer ratio of 140 kg Ca, 200 kg N, 25 kg P and 300 kg K, is to be applied on a hectare of cocoa farm to help trees grow prior to pod production.

2.3.3 Fruit Development

Afoakwa (2010) noted that the annual mean of flowers formed on a healthy cocoa tree range from 20,000 to 100,000 with a pollination rate of 1 – 5 % developing into pods. Insects involved in the pollination include aphids, midges and thrips. Orwa *et al.* (2009) described the pod formation process as starting from the completion of an effective pollination. Within a period of 36 hours after that, fertilization takes place causing the abscission of the sepals, petals and staminodes then eventually the withering of the stamens and pistils. Through longitudinal elongation, cherelles (young cocoa pods) begin to form and maturity continues with an increase in width. Depending on variety of cocoa, pod takes 5 – 6 months to mature.

The colour of a ripened cocoa fruit is subject to the genotype of the cocoa tree. A matured fruit changes colour from green or purple to a hue of red, orange or yellow (Afoakwa, 2010).

The onset of fruit bearing of the cocoa tree lies between three – four years of they been planted during which they require much attention. The cocoa tree reaches its full yielding capacity in its 10^{th} year and bears fruit even after twenty-five years of planting (Vigneri, 2008).

During a COCOBOD conference in 2015, farmers were advised to replace their cocoa trees once they hit 30 years though these trees may be bearing some fruits. This they explained will help upsurge the productivity and economic returns of the cocoa farm (COCOBOD, 2015).

2.3.4 Yield and Harvesting

According to the Food and Agricultural Organisation (2014), the yield of cocoa ranges from 300 – 700 kg ha^{-1} with a mean of 450 $kgha^{-1}$. Pang (2006) and Maharaj et al. (2005) are of the view that this yield can be boosted to approximately 3000 $kgha^{-1}$ when good farm management such as regular fertiliser and pesticide application, are practiced. Giving the level of productivity of farmers, the Cocoa Research Institute of Ghana (2015) identified three classes of producers in Ghana; the highly productive with a yield of 1400 kg ha^{-1}, the medium producers with a yield of 650 kg ha^{-1} and those with a low productivity level had a yield of 350 kg ha^{-1}. Ghana has its mean yield a little above 500kg ha^{-1} (FAOSTAT, 2016).

Unlike most plants whose fruits develop on the branches, the fruits of cocoa usually develop on the trunk of the tree. With an approximate weight of 200 g – 1 kg on a wet basis and a length range between 4 – 14 inches (100 – 350 mm) a cocoa fruit is said to have matured and ready for harvesting. To permit a uniform ripen state of pods, pods are to be harvest at frequent intervals and harvesting should be within a period of 3 weeks and advisably not more (Mossu, 1992; Adzaho; 2007, Afoakwa, 2010).

Verna (2013) mentioned that a cocoa tree would approximately produce 20 – 50 pods a year. Attached to a central placenta are seeds or cocoa beans enclosed in each pod numbering between 20 and 40.

It is advised that pods should not be harvested before they are ripened and Afoakwa (2010) asserted that pods can be left on cocoa tree for about 14 days after ripening before being considered for harvesting. Notwithstanding, pods should not stay long on the tree after ripening as the seeds will germinate and adversely affect the cocoa flavour during fermentation.

Climatic conditions and region of cocoa farm affects the time of harvest of cocoa fruit. However, there are typically two seasons of harvest with the first occurring within the months of April to June and the other period occurring in October (Zhang and Motilal, 2016).

Harvesting of the matured cocoa fruit off the stem of the tree is orchestrated by sharp hooks or cutlasses. The sharp-edged equipment prevents damage of the tree's cushion and the point at which future flowers and subsequent pods will occur (Wood and Lass, 2001).

Vos *et al*., (2003) observed that spread of fungi can be prevented by removing diseased pods with different equipment and disposed away from the healthy cocoa trees.

2.3.5 Pod Opening

Every farmer and the practice that pertains on the farm with respect to length of pod storage before breaking. BCCCA (1996) recommends a pod storage period of 6-15 days whilst CRIG advocates for a 3-4-day pod storage (Adzaho, 2007). Afoakwa (2010) added that whichever length of days employed, the basis of pod storage is to hasten the fermentation process and enhance formation of characteristic cocoa flavour.

Opening of the pod can be achieved by various means, either by hitting it against each other or with a wooden club or a blunt knife. Usually, use of sharp objects is prohibited as they could damage the seeds if not used expertly. When the pod is opened, the bean is separated from the placenta, piled in a heap and covered with banana leaves for fermentation to take place (Afoakwa, 2010; Zhang and Motilal, 2016).

2.3.6 Fermentation

There are various methods of fermentation; heap fermentation, box fermentation or tray fermentation. In West Africa and Ghana particularly, the method used is the heap method where the farmers pile the cocoa beans in a heap and turn them every 2nd and 4th day (AnimKwapong *et al*., 2006) with an average fermentation duration of 5-6 days.

The pulp serves as a rich medium for microbial action. It has an estimated sugar content of 9 – 13 % w/w, protein content of 0.4 - 0.6 %w/w and diverse organic acids which imparts a pH of between 3.0 - 3.5 to the pulp. During the fermentation of the bean, the pulp solubilises (Lima *et al*., 2011).

The fermentation process is an uninterrupted microbial action of the pulp degradation. This action causes a surge in temperature to approximately 50 °C and the formation of ethanol and lactic acid, which invariably leads to the death of the bean's embryo. Ultimately, an environment for formation of flavour and aroma precursors of chocolate is created and developed through the drying and roasting process (Cruz *et al.,* 2015).

Cocoa beans are rich in polyphenols. When the polyphenols react with sugar and amino acid present in the beans, the characteristic chocolate brown colour and flavour is imparted to the beans (Afoakwa et al., 2010).

2.3.7 Drying and Storage

After fermentation the cocoa beans are dried. Basically, there are two (2) methods of drying; either by sun drying or artificial drying (example oven). The sun drying employs the use of mats laid on the ground or raised on sticks and the cocoa beans spread on them. The beans are not covered and exposed to all things pertaining in the environment. For this reason, some advice the use of artificial means but the concern with that is, rapid drying may occur and affect the completion of the oxidative changes taking place. Also, the characteristic flavour when sun dried is not realised when other means of drying is employed as wood smoke may rather be imparted in the beans in the case of firewood oven (Amoah, 2013).

For subsequent storage and transportation, Awua (2002) advised that the moisture content of the mean should not exceed 7.5 %. The method of drying the bean (sun drying) leaves the drying duration at the mercy of the weather. The drying process could take 10-14 days or 7-8 sunny days (Amoa-Awua *et al.*, 2006). Pointers of well-dried beans are that, they have a good brown colour, would easily crack when pressed between the fingers, would not have off flavours, low astringency and bitterness (Afoakwa, 2010).

Dried cocoa beans are packed into jute sacks, tied and transported to buyers and or processors or stored under favourable condition of no water contact or pest and weevil infestation.

2.4 Products obtained from Cocoa

The seeds (beans) of cocoa can be eaten alone without any processing due to the sweet pulp surrounding it. However, after the pulp solubilises during fermentation and the bean is dried, the cocoa bean can only be consumed after further processes are carried out on it. The commonest product known of the cocoa bean is chocolate. Nevertheless, there are intermediary edible products during the chocolate production. The products obtained from cocoa beans are cocoa liquor, cocoa powder and cocoa butter.

After fermentation and drying, the processing of the cocoa beans continues with roasting. Zhang and Motilal (2016) noted that the process of developing cocoa or chocolate flavour comes to a completion when the dried cocoa beans are roasted. Afoakwa (2010) described three (3) modes through which the roasting is carried out in the cocoa processing factories; Whole bean processing, Nib roasting and Liquor roasting. Normally, the whole bean roasting is the method used. With that, the dried beans are roasted before deshelling whilst in the other two (2) methods deshelling is done before roasting.

After roasting, the beans are broken to smaller sizes and the shells are separated from the nibs through winnowing. The shells are collected and used as mulch or fertiliser whilst the nibs are alkalised (using potassium or sodium carbonate) and milled into cocoa mass (first product of dried cocoa beans). It is from the cocoa mass that all edible products are obtained from the cocoa beans (Awua, 2002; ADM Cocoa, 2006; Afoakwa, 2010; ICCO, 2013).

The cocoa mass is basically an approximate equivalent proportion of cocoa solids and cocoa butter. Melted cocoa mass is known as **cocoa liquor**. The cocoa liquor is put in a hydraulic press and **cocoa butter** gets separated from **cocoa solids** (at that stage called cocoa presscake). Cocoa liquor contains approximately 50 – 58 % cocoa butter (Ramsey, 2006; Spiegel, 2014) of which 78 - 90 % gets separated from the *cocoa presscake* after pressing (Beckett, 2000). The liquor can also be used just as it is by cooling and moulding into chunks referred to as raw chocolate (Ortiz, 2017).

The cocoa presscake is broken into smaller pieces and whence referred to as "*kibbled cake*". The kibble cake's size is further reduced by pulverising to gain **cocoa powder** (Afoakwa, 2010).

2.5 Uses and Health benefits of cocoa

2.5.1 Uses of Cocoa and its Products

No part of cocoa goes to waste. There are specified uses of the various components of the cocoa fruit, right from the pod through the bean's shell to the nib. Following the pod (husk) opening to release the beans, all pods are gathered and incinerated to produce potash. The potash is used as fertiliser for food crops or used in the production of local soft soap (AmoAwua *et al*., 2007; ICCO, 2003; CRIG, 2015). Also, ICCO (2003) asserted that the husk can be used in pelletized form in animal feed and CRIG (2015) reported of trial feeding of poultry, pig and sheep with feed formulations of the pelletized husk.

Fresh cocoa pulp juice can be used in the production of jam and marmalade, soft drinks and alcohol (ICCO, 2003).

Ghana Cocoa Board (2007) has indicated that cocoa butter can be used in treating burns, dry lips, wounds and snake bites. Also produced from cocoa are cooking fat, cocoa brandy, cocoa ointment and cocoa vinegar. Beverages can be made from cocoa powder.

The products obtained from the processed cocoa beans; cocoa liquor, cocoa powder and cocoa butter are used with other ingredients in the production of chocolate (Afoakwa, 2010).

2.5.2 Health Benefits of Cocoa

Essentially, cocoa contains nutrients such as zinc, magnesium, calcium, iron, copper, proteins, fats and carbohydrates. Cocoa also contains sulphur which helps develop strong bones and hair (Skae, 2008; Afoakwa, 2010).

Cocoa has been proclaimed as being a wealthy source of polyphenols specifically procyanidins (epicatechin and catechin). These substances confer the antioxidant, antiradical and anticarcinogenic properties on the cocoa (Beckett, 2000; Lettieri-Barbato *et al*, 2012).

The procyanidins inhibit the oxidation of LDL (low-density lipoprotein)- cholesterol which could have caused atherosclerosis (Skae, 2008). Other antioxidant effects include the inhibition of heart attacks, stroke and asthma (Wollgast and Anklam, 2000; Ghana Cocoa Board, 2007).

Taubert *et al.* (2007) reports that flavonoids present in cocoa reduces blood pressure, aids in blood circulation and imparts favourably on the organs especially the heart.

Cocoa exerts compelling effects on the central nervous system. It contains stimulants such as theobromine, serotonin, dopamine, phenylethylamine (PEA) and anandamide. These substances generally have constructive influence on one's mood and research has shown that cocoa can reduce stress in menopausal women (Kattenberg, 2000; Richelle *et al*., 2001; Skae, 2008). Anandamide (also known as “chocolate amphetamine”) is believed to decrease depression and increase mood. Serotonin which is also thought to aid in the regulation of appetite and digestion, emotions and social conduct is said to front the antidepressant effect of chocolate. PEA on the other hand is held responsible for a feel of focused and alertness incurred after consumption of cocoa (Cousens, 2001; Skae, 2008; Verna, 2013).

2.6 Economics of Cocoa

2.6.1 World Production and Consumption of Cocoa

Edoh and Ngo-Samnick (2014) observed that there is an appreciable balance in spread of cocoa production geographically with prominent growth regions as South & Central America, Asia & Oceania and West Africa.

Of the approximately 4.2 million metric tons of cocoa produced, Africa holds a 73 % share, Asia has 16 % and America, 11 %. Ivory Coast produces more than half of Africa’s share of cocoa affording it the title as the lead producer of cocoa globally (WCF, 2014; Sulaiman and Boachie-Danquah, 2017; Statista, 2017). The eight (8) leading producers of cocoa in descending order are Ivory Coast (42 %), Ghana (18 %), Indonesia (8 %), Ecuador (6 %), Cameroon (5 %), Nigeria (4 %), Brazil (4 %) and Peru (2 %) (*refer to appendix 1*) (ICCO, 2016).

There are approximately 5 - 6 million cocoa farmers across the globe. Typically, 90 % of cocoa produced is cultivated by small holder farmers. Each farm has an estimated yield of between 300 – 400 kg/ha for Africa and 500 kg/ha for Asia (WCF, 2014). In Ghana, smallholder farmers harvest cocoa on five (5) to ten (10) acres of farm and the cocoa industry engages about 60 % of the agricultural labour force (Sulaiman and Boachie-Danquah, 2017).

Cocoa production in Ghana has seen a steady increase from 778,000 tonnes in 2015/16 and 850,000 tonnes in 2016/17 to 900,000 tonnes in 2017/18.

Demand and supply of cocoa beans is measured by consumption of grindings. Cote d'Ivoire once again holds the title as the world's leading grinder of cocoa beans with 13.4 % overtaking Netherlands which was leading the previous year at 13 % now with 13.2 %. The succeeding countries are Germany (0.41 MT), Indonesia (0.4 MT), United States (0.4 MT), Brazil (0.23MT), Malaysia (0.21MT) and Ghana (0.21MT) (ICCO, 2016; *refer to Appendix 16*). The global grinding market is estimated at US$ 16 million. The leading grinding processing companies globally are Cargill, OLAM and Barry Callebaut. Aside the global grinders with representative companies in Ghana, local grinders in Ghana include Cocoa Processing Company Limited (CPC), Niche Cocoa Industries, Plot Enterprise and Real Products Limited. All but CPC and Niche process intermediary products from the cocoa beans (Sulaiman and Boachie-Danquah, 2017).

ICCO (2016) reported that, the average consumption of cocoa beans in the world is 0.63kg/person with Europe consuming most at 2.25 kg/person, Americas at 1.31 kg/person with Africans and Asians/Oceania lagging at 0.23 kg/person and 0.19 kg/person respectively.

The countries with cocoa per capita consumption above 2kg are Belgium (5.86 kg/person), Switzerland (5.69 kg/person), Germany (4.31 kg/person), Australia (3.22 kg/person), France (3.49 kg/person), UK (3.39 kg/person), Slovenia (2.94 kg/person), Netherlands (2.60 kg/person) and United States with 2.29 kg/person. Those below 2 kg include Poland (1.71 kg/person), Italy (1.64 kg/person), Japan (1.39 kg/person), Russian Federation (1.29 kg/person), Kazakhstan (1.28 kg/person), followed by the world's leading producers of cocoa; Brazil (0.93 kg/person), Cote d'Ivoire (0.61 kg/person), Ghana (0.51 kg/person) and China at 0.06 kg/person.

2.6.2 World Production and Consumption of Chocolate and Chocolate Products

The global chocolate industry is estimated at US$110 billion dollars of which Ghana and Cote d'Ivoire jointly hold 5million dollars only (Sulaiman and Boachie-Danquah, 2017; Eduku, 2017). Ghana currently has two (2) processing companies (Cocoa Processing Company and Niche Cocoa) that indulge in secondary processing of cocoa, taking the value addition a step further by producing chocolate and other confectioneries from cocoa aside the intermediary products (cocoa butter, cocoa liquor, cocoa cake, cocoa powder) produced by the other processing companies. However, the named processing companies with other smallscale processing enterprises, can process less than 30% of the cocoa beans produced in the country. Despite this low production rate, there is an even lesser consumption rate or consumer purchase of these chocolate products in Ghana. Statista (2018) report on consumption of chocolate products presented the following; Switzerland (8.8 kg/person), Austria (8.1 kg/person), Germany (7.9 kg/person), Ireland (7.9 kg/person), Great Britain (7.6 kg/person), Sweden (6.6kg/person), Poland (5.7 kg/person), United States (4.4kg/person), France (4.3 kg/person) and China (0.1 kg/person) (Statista, 2018).

United States and Germany are the leading importers of cocoa butter with United States doubling as the leading importer of cocoa powder. Subsequently, United States is the leading producer of chocolate products (Sulaiman and Boachie-Danquah, 2017).

2.7 Chocolate

2.7.1 Chocolate Composition

Cocoa beans from Ghana serve as a standard by which global commercial cocoa beans are evaluated. Marketable cocoa beans should be well fermented, thoroughly dried, free from contaminants, odourless and non-smoky to meet the International Cocoa Standards. When the beans are of this quality, their theobromine content amongst other nutrients, are in appreciable levels. Beans with high theobromine content make chocolate of high standard (Essegbey and Ofori-Gyamfi, 2012).

Basically, chocolate is obtained by passing its four main components; cocoa butter, cocoa liquor/cocoa powder, milk and sugar though various processes to obtain a fine suspension of semisolid particles in a continuous fat phase. Other ingredients added could be emulsifiers and flavours. Differences in ingredient proportion, blending techniques and processing methods impart variations in the sensory characteristics to the chocolate (Afoakwa, 2010).

There are three (3) primary categories of chocolate. They are, dark chocolate, white chocolate and milk chocolate. These categories come about due to variations in the ratio of ingredient used in the manufacturing. The names of the chocolate and their colour (appearance) helps tell them apart even before tasting. Amongst the four (4) main ingredients, an omission of milk only forms dark chocolates, whilst an omission of cocoa liquor only forms white chocolate. Milk chocolate is produced when none of the 4 main ingredients is excluded in production (Delbaere, 2013).

2.7.2 Functions of Chocolate Ingredients

2.7.2.1 Function of cocoa liquor/cocoa powder

Grinding of roasted cocoa nibs gives cocoa mass which when melted is referred to as cocoa liquor. The roasted cocoa nibs are brown in colour and this colour is imparted unto the cocoa liquor. In chocolate production, it is the addition of cocoa liquor that gives chocolate its characteristic brown colour. This explains the plain colour of white chocolate which is produced by omission of the cocoa liquor.

Cocoa liquor/ cocoa powder generally provides the cocoa flavour to the chocolate. Cocoa liquor from different sources exhibit different sensory appeal; from marked cocoa character with nutty tinges through notorious bitterness to aromatic and winy notes (De La Cruz *et al.*, 1995; Afoakwa, 2010).

Cocoa powder is the defatted component of cocoa liquor. It is usually consumed as a beverage sometimes with sugar and milk. It can also be used in chocolate making to serve the same functional purpose as cocoa liquor (Delbaere, 2013).

Both cocoa liquor and cocoa powder contain stimulants, neurotransmitters and antioxidants essential to man (Skae, 2008).

2.7.2.2 Function of cocoa butter/other fats

Primarily, the cocoa butter molecules provide the structure for solid chocolate. The smooth mouthfeel that makes consumption of chocolate a delight is attributed to the fat phase present therein. This fat phase is mostly provided by the cocoa butter used in chocolate making.

The principal fatty acids in cocoa butter are saturated stearic (18:0, 30-37 %), and palmitic (16:0, 24-30 %) and monounsaturated oleic (18:1, 29-38 %). The minor triglycerides are polyunsaturated linoleic fatty acids (18:2, 0-4 %) and arachidic fatty acid (20:0, 0-1 %) (Bracco, 1994; Kongor *et al.*, 2016). This composition is unique to cocoa butter and no vegetable oil can have this exact triglyceride combination. The composition affords cocoa butter the ability to influence the melting property of chocolate. At ambient temperatures between 20-25 °C, chocolate is solid but melts just around the body temperature of 37 °C (Whitefield, 2005).

Lipp *et al.* (2001) also noted another function of cocoa butter as imparting on the physical properties of the chocolate such as good snap and pleasant gloss. These qualities they opined that was imparted because of the crystal lattice of the cocoa butter.

According to the Cocoa and Chocolate Product Regulation (2003), other vegetable oils alternative to cocoa butter can be used in making chocolate except that it should form 5 % of the fat phase if the product is to be called chocolate. Otherwise, a total replacement of the cocoa butter no longer makes the product chocolate. Cocoa butter alternatives can be obtained from palm kernel, illipe butter, kokum butter, kernel of mango or Borneo tallow (Verna, 2013).

Typically, chocolate contains 25 - 35 % fat as anything below 23 % will produce a paste-like chocolate rather than a liquid one (Beckett, 2000).

2.7.2.3 Function of sugar

Sugar reduces the bitterness of the cocoa liquor by greatly contributing sweetness to chocolate. Sucrose is preferred to glucose and fructose, as the monosaccharides are difficult to dry. However, sugar alcohols such as sorbitol, mannitol, isomaltose, erythritol and maltitol syrup can be used. Though these sugar alcohols affect the rheological properties of the chocolate produced, such chocolates are labelled low-calorie or sugar free and appeal to consumers concerned about their calorie intake (Beckett, 2000). Water binds to sugar.

2.8.2.4 Function of milk/dairy product

Water is not included in chocolate making. Hence, all ingredients are appreciated in dry or powdery form and milk is no exception. Milk is comprised of approximately 5 % lactose, 5 % milk fat 3.5 % protein and 0.7 % minerals. The milk fat component softens chocolate texture, slows setting, adds up to the fat content of the chocolate and generally affects the shelf life of the chocolate (Haylock and Dodds, 1999; Afoakwa, 2010).

It is the milk powder that causes the colour difference between dark chocolate and milk chocolate by giving milk chocolate a lighter shade to dark chocolate (Owen, 2013).

2.7.2.5 Function of surfactants

Cocoa butter provides chocolate with a continuous fat phase which would not mix easily with cocoa solids and other hydrophilic components. Emulsifiers are hence used to generate a miscible interface between the solid particles and the cocoa butter matrix. These emulsifiers act as surfactants by preventing the coalition of the cocoa butter into tiny droplets whilst allowing it to flow. Examples of emulsifiers are gum (xanthan), lecithin (preferably soy) and polyglycerol polyricinoleate (PGPR) (Owen, 2013). Emulsifiers reduce yield stress and increase the stability of the chocolate. For thicker chocolates which will be used for mould blocks, less emulsifier is used whereas for thinner chocolates more emulsifier is used. Ideally, lecithin can only be added up to 1 % (Afoakwa, 2010).

2.7.3 Production of Chocolate

Chocolate production is characterised by five (5) main processes with each process conveying a special attribute on the chocolate. The processes are Mixing, Refining,

Conching, Tempering then ends with Moulding and Cooling.

2.7.3.1 Mixing

This starts the chocolate making process and it's the blending of all raw materials. The chocolate raw materials are in two phases; the ingredients containing the solid particles (cocoa powder/cocoa liquor, milk powder, sugar, vanilla) and the others with the fat content (cocoa butter and milk fat). The solid particles containing ingredients is mixed first, then about 24 – 27 % of the fat phase is added (Beckett, 2009).

There are two (2) types of this process. The batch mixing and the continuous mixing. The continuous mixing is typical of large chocolate manufacturing companies where automated kneaders are used for this process. The batch mixing is done over a period of 15minutes and not less than 10minutes at a temperature of 40 – 50 °C. Examples of equipment used for the batch mixing include Planetary mixer and Stephan mixer (Awua, 2002; Delbaere, 2013).

This operation is essential as it helps obtain a steady and uniform formulation for the chocolate production.

2.7.3.2 Refining

The mixture from the preceding phase is grounded in a refiner to obtain a particle size of less than 30 µm (Beckett, 2000; Beckett, 2009).

Primarily, the refining stage ensures the fine grinding of the chocolate's particulate ingredients, especially the sugar and or milk if it's not dark chocolate being produced. This operation distributes the particle in the continuous phase and coats them with the fat (Delbaere, 2013) and is generally set to produce a smooth texture for the chocolate.

There are 2 ways of undertaking the refining operation, either a single stage refining process or a two-stage refining process. The single stage refining process comprises of a first phase of separate ingredient milling followed by refining process. The two-stage refining process on the other hand uses a 2- roll pre-refiner and a 5-roll refiner to achieve the refining (Afoakwa, 2010). The sensory and rheological properties of chocolate are affected by the particle size obtained at the end of this operation.

2.7.3.3 Conching

From the refiner, the mixture is put into a conche; a shell - like machine that agitates the mixture averagely between 4-24 hours depending on the type of chocolate. This operation is carried out at a temperature above 50 °C (Beckett, 2000; Afoakwa, 2010). There are three (3) stages in this process, that is, the dry conching, the pasty phase and the liquid conching. To obtain the desired flow characteristics of the chocolate, the remaining, 4 % cocoa butter and lecithin is usually added during the liquid conching phase (Afoakwa, 2010).

According to Delbaere (2013), the main reasons for this operation are to reduce moisture and viscosity in the chocolate and to develop the appropriate chocolate structure and flavour.

There is also the removal of undesirable flavour-active volatiles.

2.7.3.4 Tempering

Afoakwa (2010) noted that the procedure for tempering is dependent on the recipe being followed, equipment used and final purpose of chocolate. This underlines the three types of tempering which are seeded tempering, tabling/hand tempering and the incomplete melting. The tabling/hand tempering is preferred since it produces glossier chocolate with good snap.

According to Beckett (2009), tempering facilitates the generation of an adequate number of seed crystals which in turn encourages the crystallisation of the entire fat phase in a more stable polymorphic form.

The tempering process starts with complete melting of the chocolate at 50 °C to clear crystal history, then cooling to a point of crystallization and finally melting out of unstable crystals. For dark chocolate, tempering is done at a temperature of 33 °C whereas the milk chocolate is tempered at a temperature of 30 °C (Afoakwa, 2010).

Characteristic of a well-tempered chocolate is the colour, glossy appearance, good contraction from mould, fewer fingerprints during packaging, which is indicative of heat resistance and extended shelf life (Whitefield, 2005; Afoakwa, 2010).

2.7.3.5 Moulding and Cooling

During tempering, the chocolate thickens as it cools and sets. It is advisable to always have a prepared mould (pre-heated to a temperature almost the same as that of the chocolate to pour inside) at hand for the tempered chocolate to be poured into. The chocolate-filled mould is left on a horizontal slab and allowed a period of 3-5 minutes to finally set and cool. The mould is then placed in cold storage to harden the chocolate and removed after 15minutes

(Awua, 2002; Afoakwa, 2010).

2.7.4 Quality Parameters of Chocolate

2.7.4.1 Sensory

Based on sensorial perception, determinants of food quality include the appearance of the food, its flavour, the texture and its nutritional value.

Before consumption, the foremost encounter with food is the appearance. Usually, the choice of food of first-time consumers is informed by the appearance of the food. For chocolate a panel of judges will look out for the legendary gloss conveyed by the fat phase, often the cocoa butter. Afoakwa (2010), described in his book good-quality chocolate as having an unceasing light to dark brown colour with a glossy appearance indicating that the white patches caused by fat and sugar bloom reduced the quality of the chocolate and interfered with the glossy look. Flavour is resultant of taste and aroma stimuli perceived off any food. Chocolates taste is largely determined by its individual ingredients. The final chocolate flavour results from post-harvest processes of the cocoa beans, and subsequent chocolate making processes. Chocolate has a distinctive cocoa aroma and hence any defect in the beans is carried on into the final chocolate. Also, the cocoa varieties have distinct flavour attributes they impart to the final chocolate flavour example, floral, malty, caramel (Afoakwa, 2010; Kongor *et al.*, 2016).

Afoakwa (2010) noted that according to the parameter being observed, that is be it structure, consistency or mouthfeel, chocolate texture is described by a myriad of words. However, there are variations in the intensity of these descriptors. Texture of chocolate could be described as smooth, adhesive, gritty, chunky or astringent. The melt rate is also indicative of chocolate texture. Per the findings of Urbanski (1992) the optimal range of refining chocolate is set between 15 µm to 50 µm since the human tongue cannot differentiate particle size below 15 µm and anything above 50 µm elicits a gritty perception.

The force exerted by the incisors on a bar of chocolate describes the hardness of chocolate as very hard if excess force is used or soft if mild force is applied (Harwood and Hayes, 2017).

2.7.4.2 Chocolate defects; fat bloom and sugar bloom

There are instances when fat crystals solidify on the surface of chocolate due to fat migration or other reasons. At those instances, light rays shining on such chocolate are disrupted with white film of fat visible on the surface of the chocolate. This sight is known as fat bloom. Fat bloom is caused by factors such as fat migration, difference in temperature of chocolate and centre, inappropriate storage conditions and recrystallisation without appropriate tempering (Afoakwa, 2010; Owen, 2013).

Sugar bloom is also expressed as a whitish film on the surface of chocolate and is sometimes confused with fat bloom. Sugar bloom is typically caused by sharp temperature difference where the chocolate is swiftly moved from a low temperature to a higher one. This causes the chocolate to sweat. However, in the sweat are dissolved sugars from the chocolate. These sugars remain on the surface of the chocolate when the sweat dries off and is seen as white patches on the chocolate (Afoakwa, 2010).

In themselves, these two defects are not harmful as they pose no threat to the health of the consumer. Albeit, they are unsightly and unprofessional hence should be avoided carefully.

Water an inexpensive and essential resource in most food production floors is vehemently avoided in chocolates. The most abundant component of chocolate, cocoa butter, is largely hydrophobic and hence does not do well when the chocolate encounters water. The other chocolate components which are hydrophilic will dissolve in the water and form clumps. This will cause the chocolate to seize and no longer have that flowable feature characteristic of chocolates (Owen, 2013).

2.8 Cocoa Butter

2.8.1 Generalities

Fundamental to the chocolate charm is the continuous lipid phase provided by the cocoa butter ingredient. Aside supporting the non-fat phase of chocolate, the fat phase (largely made of cocoa butter) has major influence on the dynamics of chocolate. The characteristic flavour release, mouth feel, gloss, heat stability and snap associated with chocolate is alluded to the fat phase. Defects such as fat migration and fat bloom are also associated with the fat phase of chocolate (Smith, 2001; Norberg, 2006).

2.8.2 Physical Properties

Cocoa butter is a triglyceride fat with three fatty acids and 1 triglyceride backbone. However, cocoa butter is polymorphous in nature due to its triacylglycerol composition. Owen (2013) explained this polymorphism as shaped as a chair with two long fatty acids on the sides of a short "seat", that is the triglyceride and another long fatty acid on the side. This uncommon shape of the cocoa butter molecules allows them to be organised into several crystalline arrangement known as forms.

Cocoa butter expresses in forms of α, β, β^1 and γ. It can crystallise into six (6) different polymorphic forms (I - VI). Form I is of the γ type, form II is of the α type, form III and IV are of the β^1 type as β^1_2 and β^1_1 respectively whilst form V is of the β_2 type with form VI being of the β_1 type. Form I and II occur at a temperature range of -5 to 22 °C. Forms III and IV occurs between 20 °C to 27 °C. Between 32 °C to 36 °C, the stable forms V and VI occur. Though both stable, form V is the most desired in chocolate making as form VI is characteristic for fat bloom (Timms, 2003).

The chocolate must be tempered to obtain the desired polymorphic form. Beckett (2000) described a well-tempered chocolate as one that appears glossy, has good snap, easy contraction from mould and is resistant to bloom.

The melting profile of cocoa butter is quite steep and depending on the polymorphic form present in the cocoa butter the temperature range of melting is from 15 °C to 36 °C. This steep melting profile causes the cocoa flavour to be released within a rather short period producing a bust of intense flavour. As heat is absorbed from the mouth during mastication to melt chocolate, there is a cooling sensation which is orchestrated by the steep melting profile (Smith, 2001).

Fatty acids crystallise in a double-chain or a triple-chain form depending on the triglyceride composition and positional distribution. Form IV crystallises in a double-chain form whilst form V crystallises in a triple-chain system. The triple-chain form of crystallising enables closer packing and greater thermodynamic stability. Chocolates with crystals of a higher form is glossier and harder creating a good snap (Owen, 2013).

2.8.3 Chemical Properties

Chocolate triglycerides are esters of three (3) fatty acids linked to a glycerol backbone. Cocoa butter's origin determines the ratio of fatty acids present. Cocoa butter is dominated by saturated stearic (18:0, 30 - 37 %) and palmitic (16:0, 24 - 30 %) and monounsaturated oleic (18:1, 29 - 38 %). It also contains minor triglycerides such as polyunsaturated linoleic fatty acid (18:2, 1 - 4 %) and arachidic fatty acid (20:0, 0 - 1 %) (Bracco, 1994; Smith, 2001; Kongor *et al*., 2016).

Cocoa butter contains roughly 40 – 50 different triacyclglycerols (TAGs) mainly of 2-oleyl glycerides of palmitic and stearic acids. The TAGs have a central monounsaturated fatty acid in symmetric triacylglycerols. They have mono-saturated fatty acids in the 1 and 3 positions which direct the polymorphism, crystallisation and phase transformation of cocoa and chocolate. This attribute is responsible for the characteristic textural and sensory properties of chocolate (Afoakwa, 2010).

Depoortere (2011) mentioned the main triacylglycerols as 1,3-dipalmioyl-2-oleoyl-glycerol (POP), *rac*-palmitoyl-stearoyl-2-oleoyl-glycerol (POSt) and 1,3-stearoyl-2-oleoyl-glycerol (StOSt). Afoakwa (2010) however describes 1-palmitoyl-2-oleoyl-3-stearoylglycerol (POS) 35 %, 1,3-distearoyl-2-oleoylglycerol (SOS) 23 % and 1,3-disaturated-2-oleoylglycerol-type, 1,3-dipalmitoyl-2-oleoylglycerol (POP) 15 % as the main TAGs in cocoa butter. Due to this triacylglycerols composition, cocoa butter quickly melts over a narrow temperature range.

2.8.4 Quality indices of cocoa butter

Selinger *et al.*, (2017) recommends the measurement of primary and secondary oxidative products as a means of fats and oils quality assessment. Generally, Peroxide Value (PV), free fatty acids (FFA) value and p-anisidine value (p-AV) are used to evaluate the oxidative products of oil, whereby PV and FFA measures the primary products whilst p-AV measures the secondary products.

When oxygen reacts with the double bonds of a fatty acid, peroxides and hydroperoxide (primary product of oxidation) may form. Peroxide value is the milliequivalent of peroxide oxygen per 100g of fat. Usually, fresh oils are expected to have PV less than 10 per gram of a fat sample (Gordon, 1993).

Oil with low PV is said to be of good quality and indicative of proper handling and preservation (exposure to high temperature, oxygen and light) of the oil whilst a high value is indicative of rancid oil. Nevertheless, an oil sample may record a low PV if oxidation is in the advanced stage. Low PV hence denotes the initial or final stages of oxidation (Miller, 2010).

A break in the ester linkage of a triacylglycerol's backbone causes the release of fatty acids from the molecule. The free fatty acids present in a given fat is measured as the free fatty acid value. FFA value is the percentage by weight of a specified fatty acid (Selinger *et al.*, 2017).

According to CODEX STAN 86-1981, cocoa butter should not have an FFA value more than 1.75%m/m expressed as oleic acid. Oils with low FFA value are said to be of good quality whereas high values are indicative of rancid oils.

High FFA values can be due to microbial activity or hydrolytic breakdown. Oxidation in oils can be regulated by controlling the amount of light, oxygen and moisture the oil is exposed to, introduction of transition metals and high temperatures (Miller, 2010).

2.9 Cocoa Butter Alternatives

Though cocoa butter imparts incomparable properties to chocolate, other vegetable fats can be used in chocolate production. These fats are either used as the sole fat phase in the chocolate or are added to the cocoa butter in specified proportion. Such fats are referred as Cocoa Butter Alternatives (CBA) (Kerti, 1998).

CBA's are differentiated based on their functionality, chemical and physical comparison to cocoa butter (Kerti, 1998; Depoortere, 2011). According to Kerti (1998), CBA's are grouped into two (2) factions; that is tempering fats and non-tempering fats. The tempering fats require tempering during chocolate production whilst the non-tempering fats, due to their ability to crystallise into the desired polymorphic form when cooled, do not require tempering. Also, tempering fats have similar chemical composition to cocoa butter whereas non- tempering fats are entirely different in that regard.

The tempering fats are further classified as Cocoa Butter Equivalents (CBEs) and Cocoa

Butter Improvers (CBIs). Non-tempering fats on the other hand are grouped into Cocoa Butter Replacers (CBRs) and Cocoa Butter Substitutes (CBSs). The diagram below summarises the classification of CBA's as described by Kerti (1998).

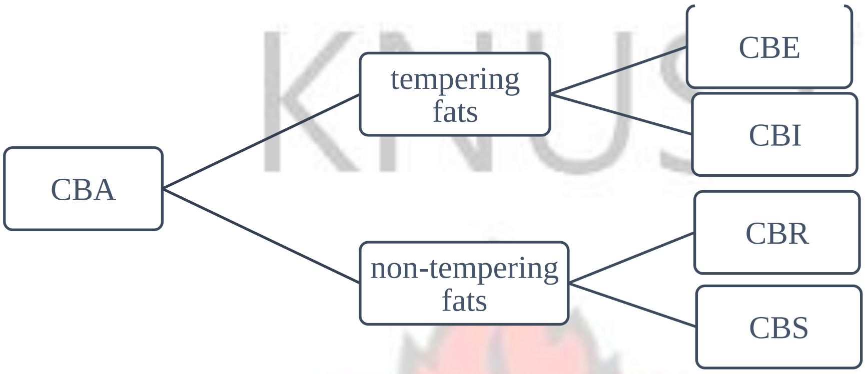

Figure 2.9 Classification of cocoa butter alternatives

Depoortere (2011) however, classifies CBI's in a sub-group of CBEs with another group known as Cocoa Butter Extenders (CBEXs). He explained that the CBEXs have specific quantities or ratios at which they can easily mix with cocoa butter whereas the StOSt content of the CBI's are high. Lipp and Anklam (1998a) asserted that the high level of StOSt of CBI allows their use in improving soft cocoa butter by making them hard.

When added to chocolate, the CBI's impart favourable qualities such as increase in melting point of chocolate, resistance to fat bloom at high temperatures and increase in hardness of chocolate. Examples of CBIs include illipe butter, shea butter and kokum fat (Timms, 2003; Maheshwari and Reddy, 2005, Rios *et al.*, 2014).

In Lipp and Anklam's (1998a) review of cocoa butter, they described CBRs as non-lauric fats with an entirely different triglyceride structure (such as PEE, SEE) which are miscible with cocoa butter in small proportions. Comparatively, CBRs compatibility with cocoa butter is between that of CBEs and CBSs as it has a similar fatty acid profile as cocoa butter. CBRs are obtained from palm oil extracts. Examples of CBRs are soya bean oil, rapeseed oil and cotton seed oil (Naik and Kumar, 2014).

CBSs are utterly incompatible with cocoa butter. This is attributed to the fact that CBSs contain lauric acid and has a totally different chemical structure to cocoa butter though it maintains some physical similarities with cocoa butter (Kerti, 1998; Depoortere, 2011). Due to their immiscibility with cocoa butter, CBSs are used to completely substitute cocoa butter in confectionery industry. CBSs are used as used as 'chocolate' coating, making of fondants and jellies (Depoortere, 2011). Cooper *et al.*, (1990) named major triglycerides in CBSs as LLL, LLM and LMM.

2.9.1. Advantages and Disadvantages of CBAs

Some advantages of CBAs are outlined in the following (Kerti, 1998; Rios *et al*., 2014):

- They are relatively cheaper hence provide a cost-effective production line of chocolate
- They boost chocolate's ability to withstand tropical climates, especially the CBIs
- They increase the shelf life of the product because they have good oxidative stability
- Provides admirable gloss and can retain the gloss
- Some do not require tempering
- They impart favourably on the rheological and sensory properties of the chocolate
- CBSs solidifies quickly whether tempered or untempered.

Some disadvantages of CBAs are outlined in the following (Timms, 2003; Norberg, 2006; Talbot, 2009; Depoortere, 2011):

- Some especially the CBSs have a relatively low milk fat tolerance
- Some, especially the CBRs are high in trans fatty acids

- The CBAs with lauric acid tend to have a soapy flavour when such fats are exposed to moisture and lipase due to hydrolysis. However, the non-lauric ones have no danger of soapy flavour.

2.9.2. Properties and Laws Governing CBAs

The European Union in 2000 laid out guidelines concerning the use of other vegetable fats in chocolate production. In the EU Directive 2000/36/EC, the characteristics of vegetable fats allowed in chocolate products were laid out as follows:

- they vegetable fats are to be non-lauric and rich in symmetrical monounsaturated triacylglycerols of the type POP, POSt and StOSt;
- they are to be miscible in any proportion with cocoa butter and compatible with its physical properties (melting point and crystallization temperature, melting rate, need for tempering phase);
- they are to be obtained only by the processes of refining and/or fractionation, which excludes enzymatic modification of the triacylglycerol structure.

From the above guidelines, CBEs are the preferred choice amongst the CBAs since the others may contain lauric acids or are not miscible at any proportion.

Basically, CBEs are non-lauric fats from plants with similar physical and chemical properties as coca butter. They can be blended with coca butter at any proportion and do not alter the properties of cocoa butter when mixed (Lipp *et al*., 2001).

The EU Directive 2000/36/EC was amended on 3rd August 2003 to the effect that only six vegetable fats are allowed in chocolates as CBAs. These vegetable fats are illipe/Borneo tallow, shea, palm oil, sal, kokum gurgi and mango kernel.

FAO/WHO (2003) asserted that to maintain the name chocolate for a product despite the addition of other vegetable fats, the CBA added must not be more than 5 % based on the finished product's weight. However, such products should indicate on their labels that other vegetable fats are added to the cocoa butter.

Despite this directive by the EU, other countries have varying regulations in connection to their chocolate production and the fats allowed therein. In the United States of America, no other vegetable fat is allowed in chocolate aside cocoa butter though these vegetable fats are allowed in chocolate coatings. In accordance with the EU Directive, some countries allow more that 5 % CBAs in their product provided the product would not be named chocolate

(Talbot, 2009; Depoortere, 2011).

2.9.3 Sources of Cocoa Butter Equivalents (CBEs)

2.9.3.1 Palm oil (*Elaeis guineensis*)

This oil is extracted from the nuts of the palm tree and comprises mainly of POP and POO. Approximately 80 % of the fatty acids are oleic and palmitic acid. To concentrate into specific triacylglycerols, palm oil can be fractionated into palm olein and palm stearin (Bockisch, 1998; Depoortere, 2011). Timms (2003) opined that the palm olein fraction can further be fractionated into soft palm mid-fraction (PMF) and hard PMF (the stearin fraction of the soft PMF). Hard PMF is usually used in production of chocolate and other confectionery products (Vereecken, 2010).

Extraction of oil from the nuts' flesh can be done with or without solvent. Typical solvents used are acetone, hexane and 2-nitropropane (Bockisch, 1998; Depoortere, 2011).

2.9.3.2 Shea butter (*Butyrospermum parkii*)

The shea tree is predominant in West Africa with Ghana and Burkina Faso being leading producers. Commercial quantities of fruits from the shea tree can only be harvested after approximately 15 – 20 years of cultivation. This long maturity period makes it unsustainable for some farmers or large-scale operators. The fruits produced are nuts from which shea butter can be obtained. Shea butter is also referred to as Galam butter or Karité butter (Lipp and Anklam, 1998a, Timms, 2003; Alander, 2004; Depoortere, 2011).

As stated by Alander (2004), the fatty acid composition of shea butter is as that of cocoa butter with the occurrence of oleic acid, stearic acid, palmitic acid and linolenic acid. Shea butter has comparatively high amount of saturated acids which accounts for its semi-solid to solid state at ambient temperature. Dominating its fatty acid composition is stearic and oleic acid with a total of 40 – 45 %.

A study conducted by Di Vincenzo *et al* (2005) showed SOS and SOO as the abundant combination of triglyceride present in shea butter. The abundance of these triglycerides makes the fractionation and subsequent crystallisation of shea stearin from its olein counterpart easier. The shea stearin is found to contain 2-oleoyl-distearin and often used in

CBEs mixtures since the raw shea butter has low SOS (Lipp and Anklam, 1998; Alander, 2004).

2.9.3.3 Mango kernel (*Mangifera indica* / *Mangifera sylvatica*) fat

Jahurul *et al*., (2012) mentioned mango kernel fat as one of the few tropical fruits fats considered as a CBA. They added that the mango kernel holds approximately 7-15% fats and just as cocoa butter is rich in fatty acids such as palmitic, oleic and stearic acid. Triglycerides present in the mango kernel fat include POS (10 – 16 %), SOS (25 – 59 %), POP (1 - 8.9 %). Due to the 7 – 15 % fat content present in the mango kernel, Timms (2003) observed that solvents are usually used to extract the fat to obtain high levels of SOS. The oil is usually refined before use.

2.9.3.4 Sal (*Shorea robusta*) fat

Sal fat is obtained from the kernels of several trees that grow in Borneo, Philippines, Java and other localities. It is sometimes referred to as Borneo tallow or tengkawang tallow (Lipp and Anklam, 1998a).

The Sal kernel contains 14 – 18 % of fat which is usually solvent extracted. The fat has fatty acids comparable to that of cocoa butter with a significant amount of arachidic acid. The fat with a 56 % of SOS can be fractionated and refined to obtain more of this triacylglycerol (Storgaard 2000; Timms 2003).

In Jahurul *et al*. (2012), Sal fat was described as a green coloured fat. EU Regulation 2003 reports that though the colour 'defect' of Sal fat can be altered through a lightening process, it is still avoided in the chocolate and confectionery industry because, the process is energy intensive and costly hence most confectionery industries avoid this fat altogether.

2.9.3.5 Kokum butter *(Garcinia indica)*

Another name for this butter is Goa butter. Kokum butter is typically obtained from the seeds of the Kokum fruit by boiling the kernels in water and skimming the oil off the surface. The kernel contains approximately 45 % fat of which 73 % is SOS, 12.1 % is SOO and 8.1 % of POS (Lipp and Anklam, 1998; Timms, 2003). This fat can be used in chocolate production without fractionating but must be refined before use. Refining comes with high level of StOSt (Timms, 2003; Depoortere, 2011). Reddy and Prabhakar (1994) disclosed that kokum butter is of a grey colour and is usually used in CBE blends with other fats.

2.9.3.6 Illipé (*Shorea stenoptera*) butter

Illipe fat is a general name given to fat derived from oil bearing nuts in East Malaysia, but in commerce, Illipe refers to products from the *Shorea stenoptera* tree. Just as every other of the CBEs, illipe fats has similar composition to that of cocoa butter with stearic acid being dominant (Lipp and Anklam, 1998).

Timms (2003) interjected that this fat is high in POSt and StOSt and is preferably refined before use in the confectionery industry.

2.9.4 Production of CBEs

Depoortere (2011) affirmed that CBE can be attained via two ways, that is, either by interesterification or by blending. CBE can be made through interesterification either chemically or enzymatically. However, the EU Regulation (2003) directed that CBEs obtained by enzymatic interesterification cannot be used in chocolate production.

2.9.4.1 Chemical Interesterification

Depoortere (2011) mentioned that Unilever and Procter & Gamble have each patented a chemical process for obtaining CBEs.

The first patented process which was established by Procter & Gamble, is done by reacting hydrogenated palm oil and soya bean blend with glycerol to attain 1,2-diglyceride and 1,3diglyceride mixture. Hexane is used to gradually crystallise the 1,3-diglyceride out of the mixture. Oleyl chloride or oleic anhydride is then used to react with the palmito/stearodiglyceride (Volpenheim, 1980; Depoortere, 2011).

Timms (2003) and Padley *et al.* (1981) recounted the patented process of Unilever that it was like that of Procter & Gamble except that in this process, to obtain the 1,3-diglyceride, solid state isomerization is used rather than hexane or any solvent for that matter.

2.9.4.2 Enzymatic Interesterification

This process has been noted as a complex one due to the many stages it entails. At the onset of the process, all reactants (that is the fatty acids) must be produced then the interesterification process follows. After that distillation is carried out followed by solvent fractionation then a refining process ends it. This complex process among other things have accounted for the lack of extensive use of the enzymatic interesterification in the confectionary industry (Timms, 2003; Depoortere, 2011).

Another factor that accounts for the lack of commercial use of the enzymatic interesterification is the by-products resulting from the process. Timms (2003) reported that water used to activate the enzymes for this process produces by-products which reduce the final product yield when not removed.

The enzymatic interesterification uses lipases from microorganisms such as *Mucor*, *Aspergillus* or *Rhizopus* species. During the enzymatic interesterification process, lipases that will catalyse the reaction solely at the 1- and 3- positions of the glycerol to create StOSt triacylglycerols are used. Examples of substrates used are palm oil, high oleate sunflower oil or oleate rapeseed oil (Smith, 2001; Depoortere, 2011).

Timms (2003) mentioned that in some process triacylglycerols are reacted with fatty acids at different moisture content range from 0.2 % to 1.0 %.

2.9.4.3 Blending

This process involves mixing portions of various oils. Smith (2001) mentioned that all fats to be blended need to be in the liquid state. Also, care should be taken to avoid the introduction of so much air into the oil blend and amble time is required to ensure a homogenous mixture is obtained.

There is not a known natural fat that has much POSt as cocoa butter and hence no matter the blends, no CBE can be exact as cocoa butter (Smith, 2001; Timms, 2003). Despite, different fats forming the CBEs are added for various reasons. Example, shea fats as CBE improves the heat stability of chocolate due to its high StOSt content and PMF with high POP gives a softer texture to the chocolate (Norberg, 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Acquisition of Raw Materials

Cocoa butter used was obtained from Cocoa Research Institute of Ghana (CRIG). Cocoa butter equivalent was obtained by blending crude shea stearin (from Ghana Nuts, Techiman) and palm olein (from Frytol). Cocoa powder (golden tree brand), sugar and milk powder were obtained from the market.

For the CBEs, Design Expert 11 Software (Response Surface Method (RSM)) was used to formulate the ratio at which the blends of shea stearin and palm olein were to be made. Ten (10) variations/ratios resulted which are shown in Table 3.1.1 below.

Table 3.1: Various ratio of Shea stearin and Palm olein to be combined for the Cocoa Butter Equivalent production

Sample Number	Stearin (%)	Olein (%)
CBE 1	65.00	35.00
CBE 2	60.00	40.00
CBE 3	63.33	36.67
CBE 4	61.67	38.33
CBE 5	65.00	35.00
CBE 6	60.00	40.00
CBE 7	65.00	35.00

CBE 8	62.50	37.50
CBE 9	61.25	38.25
CBE 10	63.75	36.25

Exact amount weighed is shown in appendix 4

The blending technique was used to obtain the CBEs for the chocolate formulation. First, the shea stearin and palm olein were melted to erase all crystal history. The oils were weighed, first the stearin then the palm olein, and carefully mixed to obtain the cocoa butter equivalents.

3.2 Physicochemical Characterization of Cocoa Butter and Cocoa Butter Equivalents

3.2.1 Specific Gravity (Relative Density)

Specific gravity of cocoa butter and CBE was measured using a 50 mL capacity density bottle as done by Okezie (2007). To calculate the specific gravity, specific measurements were made and labelled as follows; the weight of the dry empty density bottle denoted ‘a’, the weight of dry density bottle with water denoted ‘b’, and the weight of the dry density bottle filled with oil, denoted ‘c’. The last process was carried out for each of the ten blends separately. The specific gravity was thence calculated using the formula below:

$$\text{Specific gravity} = \frac{\text{density of oil (cocoa butter / CBE)}}{\text{density of water}} = \frac{c - a}{b - a}$$

3.2.2 Refractive Index

Refractive indices of the cocoa butter and the various blends were measured using a refractometer (Reichert AR200 Digital Refractometer, Catalog No 13950000) in accordance with AOAC Method 9.32.14C (AOAC, 2007). The temperature of the refractometer was set up and maintained at 25 °C while being used. Droplets were added to the measuring prism with the aid of disposable pipettes. The reading was then recorded. Between samples, the surface of the prism was cleaned with non-abrasive wipes, rinsed with water then ethanol.

3.2.3 Peroxide value

Peroxide value of the various oils was measured following AOAC Method 942.27 (2007) with modifications. All samples solid at room temperature were melted. Two 250 mL capacity Erlenmeyer flask were obtained and 1g of oil sample (weighed to 0.002 accuracy) was weighed into each flask. The following reagents were then added to the sample: 20 ml acetic acid-chloroform mixture, 500 µL saturated potassium iodide solution, 10ml of distilled water and 0.5 ml of 1 % starch solution (freshly prepared). The resultant purple to dark brown colour was carefully titrated against 0.01N sodium thiosulphate solution. A change in colour of mixture to ivory or white was noted as the endpoint and stop of titration. Volume of titrant used was recorded. All reagents are added to form a mixture omitting only the oil and titrated as blank sample. The volume of titrant used was also recorded. Peroxide value was calculated by the formula below:

$$\text{Peroxide value (mEq/kg)} = \frac{(Vs - Vb) \times T \times 1000}{m}$$

where, 'Vs' is the number of mL of standardized sodium thiosulphate used when sample is contained in flask, 'Vb' is the volume titrant used when no oil sample is present, 'T' is the exact normality of the sodium thiosulphate used and 'm' is the mass in grams of the oil portion used.

3.2.4 Free fatty acid value

Free fatty acid was measured according to the AOCS Official Method (2009) with modifications. All samples solid at room temperature were melted and 0.5g of oil accurately weighed into 250 mL capacity Erlenmeyer flask. Added to this was 20 ml neutralised alcohol and mixture slowly titrated against 0.01M NaOH until pink colour appeared and lasted for some seconds. The volume of the titrant used was recorded. Free fatty acid value was calculated as follows:

$$\text{Free fatty acid} = \frac{V \times T \times MW \times 100}{m \times 1000}$$

where, V = volume of alkali used

T = normality of titrant (NaOH)

MW= molecular weight of predominant acid

MW of some acids area as follows: Oleic – 282.5, Lauric – 200.0, Stearic – 184.5, Linoleic – 280.5, Palmitic – 256.4

3.3 Chocolate Production

3.3.1 Ingredients

The main ingredients for making chocolate are cocoa mass, cocoa butter, lecithin and sugar. This forms dark chocolate. Depending on the type of chocolate wanted, an ingredient may be omitted, or another added. The addition of milk powder to the four basic ingredient forms milk chocolate whilst an omission of cocoa mass with addition of milk powder forms white chocolate. To produce the reference milk chocolate for this work, the recipe in Table 3.3.1 below was used:

Table 3.2: Ingredients and their proportion as used in chocolate formulation (Reference recipe)

Ingredient	Amount (mass %)
Cocoa mass	30.0
Cocoa butter	29.6
Sugar	25.0
Milk powder	15.0
Lecithin	0.30
Vanilla	0.10

The CBE used for the chocolate were obtained by mixing shea stearin and palm olein at ratios developed with the RSM tool on the Design Expert Software. The ratio is shown in Appendix

3, each CBE is represented as RUNs. The refractive index and relative density of all the 10 CBEs and cocoa butter were statistically analysed with the SPSS 20.0 software package (specifically One Sample T-test) to evaluate significant differences between the CBEs and the cocoa butter. Two (2) CBEs (CBE 8 and CBE 9) showed no significant difference with cocoa butter both in their specific gravity (relative density) and refractive index. Thus, the 2 were used for chocolate formulation and subsequent analysis.

The 2 selected CBEs were then blended with cocoa butter and used to make the chocolate. To obtain a 5 % replacement of cocoa butter on product base, the blends comprised of 83.17 % cocoa butter and 16.83 % of CBE. The blends were made by first melting the fats in the oven at 70 °C for an hour. This was done to erase all crystal history of the fats. The oils (that is, the cocoa butter equivalents and the cocoa butter) were accurately weighed and carefully mixed to obtain the final blends. Using the reference recipe, the blends were then used in place of the cocoa butter to make the chocolate.

3.3.2 Production Process

Before the chocolate making process, all ingredients are prepared into suitable states. Thus, the sugar and milk powder are ground to reduce the particle size. They are then sieved using AS 200 Retsch sieve to obtain materials of particle size 45 µm.

Typically, cocoa masse is used in the production of chocolate. Cocoa mass comprises of 50 58 % cocoa butter and 42 – 50 % cocoa powder (Ramsey, 2006; Spiegel, 2014). For this work, cocoa powder was available, hence cocoa mass was subsequently developed with the addition of cocoa butter to the cocoa powder. This was achieved by first melting the cocoa butter, then adding cocoa powder to the melted butter whilst stirring intermittently to obtain a smooth mass.

To undergo the first stage of chocolate production which is the mixing process, the developed cocoa mass was placed in a water bath. The blended and sieved milk powder was added and

mixed thoroughly before the addition of the blended and sieved sugar which was also mixed thoroughly. A greater portion (about 80 %) of the cocoa butter earmarked for the formulation was added to the mixture to increase its flowability. In absence of a refiner, a homogeniser was used to further reduce the particle size and enhance the texture of the mixture. The mixture was homogenised at 513 rpm at 50 °C for an hour and half. Improvising as a conche, a shaking water bath was used to reduce the moisture content of the mixture and enhance the flavour component. The mixture was allowed in the shaking water bath for a period of 5 hours. Lecithin was dissolved in the remainder of the cocoa butter weighed for the chocolate formulation and added to the chocolate mixture 30 minutes before the conching period was due (Beckett, 2009). The temperature of the shaking water bath was set at 60 °C. After conching, the chocolate mixture was tempered. Tempering was done by pouring 2/3 of melted chocolate on a marble slab and with a scraper, chocolate was turned for 10 – 15 minutes till temperature was about 25 °C. The chocolate was then added to the 1/3 untempered chocolate and stirred till a stable temperature of 30 °C consistent with milk chocolate was reached. The tempered chocolate was then poured into warm moulds, covered and placed in the refrigerator to solidify. Moulds were brought out of refrigerator after 20minutes and chocolates demoulded. The demoulded chocolates were wrapped in
aluminium foil and kept for further analysis.

3.4. Sensory analysis

The sensory analysis was carried out in an aerated and well-lit evaluating room.

Basically, the objectives of this study were to evaluate first, whether there is an identifiable difference between chocolate made with only CB and that made with 5 % CBE replacement on product base and secondly to assess consumer acceptability of chocolate made with CBE.

Based on the above, 2 tests were employed, that is, a discriminatory objective test (difference from control test) and an affective (acceptance) subjective test (hedonic rating test). Samples were kept at room temperature 5 minutes before evaluation. Samples were served to panel on a disposable plate. Water and crackers (biscuit) were provided as palate cleansers.

3.4.1 Demographics

Balanced block design for a three-product test described by Stone and Sidel (2004) in their book, *Sensory Evaluation Practices*, was used as the experimental design in this study. Based on this design, 36 subjects were used for the sensory analyses and a specified serving order developed. People available were screened using a questionnaire shown in Appendix 5 and based on that subjects were selected.

Of the subjects used in this study, 44 % were females and 56 % males. Subjects were grouped into the age ranges of 15 - 20 years, 21 - 26 years, 27 - 32 years, 33 - 39years. Majority (53%) of the respondents were within the 21 - 26 years age range, whilst the age range of 33 39 years had the least representation of 3 %. The other age ranges were represented as follows: 15 - 20 (33 %) and 27 - 32 (11 %).

3.4.2 Difference from control test

The panel evaluated three (3) chocolate samples, one reference chocolate with cocoa butter only as the fat phase (control sample) and two chocolate samples containing 5 % CBE on product base with variation in proportion of shea stearin and palm olein. Thus, CBE 8; 62.5 % stearin: 37.5 % olein and CBE 9; 61.25 % stearin: 38.75 % olein.

The taster had to assess how different each of the two CBE chocolate samples (thus chocolate made from CBE 8 and CBE 9) was from the reference (control) chocolate.

The questionnaires used to evaluate the chocolate samples are shown in Appendix 6.

3.4.3 Acceptance test: Hedonic ratings test

Presented on a plate were three pieces of chocolate samples two with 5 % CBE on product base and one with CB only. Each was differently labelled with a three-digit random code.

The assessors had to taste and rate on a 9-point hedonic scale how much they liked or disliked each chocolate sample.

The questionnaire used to evaluate the chocolate samples is shown in Appendix 7.

3.5 Statistical Analysis

All data were analysed using SPSS version 20.0 One sample t-test was used to evaluate the 10 different ratios of cocoa butter equivalents (palm olein and shea stearin blend) and cocoa butter to know at which ratio of CBEs (palm olein and shea stearin blend) will no significant difference (at a P-value of 5 %) be observed to cocoa butter.

Ratios of CBEs that showed no significant difference were subsequently used in the chocolate formulation.

Data from sensory analysis was statistically evaluated using One-way ANOVA.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physicochemical characteristics

4.1.1 Specific gravity (Relative density)

Relative density is the ratio of the density of a substance or object to that of water. The relative density measurement was to ascertain which cocoa butter equivalent formulation was comparable to cocoa butter. Relative density gives information on the identity of the oils as well as helps detect adulterations (Hamilton and Rossell, 1986).

Table 4.1 below shows the relative densities of cocoa butter and cocoa butter equivalents (shea stearin and palm olein) at 28 °C.

Table 4.1: Relative densities of Cocoa Butter and Cocoa Butter Equivalents (shea stearin and palm olein)

SAMPLE	SPECIFIC GRAVITY
COCOA BUTTER	0.907±0.000[a]
CBE 1	0.962±0.087[a]
CBE 2	0.902±0.002[a]
CBE 3	0.911±0.001[a]
CBE 4	0.938±0.065[a]
CBE 5	0.993±0.128[a]
CBE 6	0.911±0.004[a]
CBE 7	0.953±0.058[a]
CBE 8	0.906±0.001[a]
CBE 9	0.908±0.000[a]
CBE 10	0.950±0.056[a]

Values are average of duplicate determination. CBE=cocoa butter equivalents (stearin: olein). 1= (65: 35) g, 2= (60: 40) g, 3= (63.33: 36.67) g, 4= (61.67: 38.33) g, 5= (65: 35) g, 6= (60: 40) g, 7= (65: 35) g, 8= (62.5: 37.5) g, 9= (61.25: 38.75) g, 10= (63.75: 36.25) g. Values with the same superscript showed no significant difference ($p > 0.05$).

CBE 5 with an average and standard deviation of 0.993±0.128 was the highest followed by

CBE 7 with 0.953±0.058. The lowest average recorded was 0.902±0.002 of CBE 2. The CBE 8 was the second lowest with 0.906±0.001, keenly followed by cocoa butter at 0.907±0.000. Despite these differences realised in the values, the cocoa butter equivalents formulated was not significantly different from cocoa butter ($p>0.05$). This could imply that the variable stearin and olein proportions had no effect on the relative density of the oil. Hence, based on the relative density alone, any of the cocoa butter equivalents formulated can be used together with the cocoa butter to produce chocolate.

The relative densities of all the cocoa butter equivalents (shea stearin and palm olein at different ratios) showed no significant difference from cocoa butter with a value of 0.907. The relative density of 0.907 was in accordance with the relative density range of 0.8-1 reported by Gordon (1993) for most vegetable oils but lower than the value (0.921±0.011) obtained by Okezie (2007).

4.1.2 Refractive index (RI)

Refractive index (RI) is the ratio of the speed of light in a vacuum to the speed of light through a given material. Each substance has a specific RI therefore, its measurement serves as a means of identification and a measure of purity of a substance. In an oil sample, RI is an indicator of the level of saturation of the oil, the extent of oxidative damage and stability of oil after thermal treatment (Olajumoke, 2013).

For the purpose of this study, RI values for cocoa butter and cocoa butter equivalents were measured to communicate how comparable the CBE samples were to the cocoa butter. Table 4.2 below displays the refractive indices of cocoa butter and cocoa butter equivalents.

Table 4.2: Refractive Indices of Cocoa butter and Cocoa butter equivalents shea stearin and palm olein) at 25 °C

SAMPLE	REFRACTIVE INDEX

COCOA BUTTER	1.4622±0.0001[a]
CBE 1	1.4649±0.0008[c]
CBE 2	1.4643±0.0001[bc]
CBE 3	1.4644±0.0001[bc]
CBE 4	1.4643±0.0002[bc]
CBE 5	1.4644±0.0001[bc]
CBE 6	1.4644±0.0001[bc]
CBE 7	1.4643±0.0000[bc]
CBE 8	1.4636±0.0012[abc]
CBE 9	1.4629±0.0003[ab]
CBE 10	1.4643±0.0001[bc]

Values are average of duplicate determination. CBE=cocoa butter equivalents (stearin: olein). 1= (65: 35) g, 2= (60: 40) g, 3= (63.33: 36.67) g, 4= (61.67: 38.33) g, 5= (65: 35) g, 6= (60: 40) g, 7= (65: 35) g, 8= (62.5: 37.5) g, 9= (61.25: 38.75) g, 10= (63.75: 36.25) g. Values with the same superscript showed no significant difference ($p > 0.05$).

The CBE 1 had the highest refractive index with a value of 1.4649±0.0008 followed by 1.4644±0.0001 of CBE 3, CBE 5 and CBE 6. The lowest refractive index was recorded by cocoa butter with a value of 1.4622±0.0001 followed by CBE 9 with 1.4629±0.0003.

CBE 1 was significantly different from cocoa butter (1.4622) and CBE 9 (1.4629).

CBE 2, CBE 4, CBE 7 and CBE 10 which recorded the same value of 1.4643 were found not to be significantly different from CBE 3, CBE 5 and CBE 6 which had a refractive index of 1.4644.

CBE 8 with a refractive index of 1.4636±0.0012 showed no significant difference from all the samples (both cocoa butter equivalents and cocoa butter).

From table 4.2 above, cocoa butter equivalents labelled CBE 8 and CBE 9 were the only ones that showed no significant difference to cocoa butter ($p > 0.05$) whose refractive index was 1.4622.

The two samples that showed no significant difference exhibited a decrease in stearin concentration as its olein concentration increased; CBE 8 (62.50: 27.50) and CBE 9 (61.25: 38.75). Cocoa butter's refractive index of 1.462±0.000 in this study is comparable to the refractive index of 1.463±0.003 Okezie (2007) recorded for cocoa butter but higher than the 1.447 of Chinaka and Amewu (2018). Since CBE 8 and CBE 9 showed no significant difference with cocoa butter, they were used in subsequent analysis and chocolate formulation.

4.1.3 Peroxide Value (PV)

Raw materials of every food product need to be in good state before its use in food production. Peroxide value of cocoa butter equivalents and cocoa butter were analyzed to know their oxidative state before use in the chocolate formulation.

Generally, fresh oils are expected to have PV less than 10 per gram of a fat sample (Gordon, 1993). Table 4.3 below shows the peroxide values of the different oils used in the chocolate formulation for the study.

Table 4.3: Peroxide values of cocoa butter and cocoa butter equivalents used in chocolate formulation

SAMPLE	PEROXIDE VALUE ($meq\ O_2/kg$)
Cocoa butter	$1.489{\pm}0.7^{a}$
CBE 8	$2.490{\pm}0.7^{a}$
CBE 9	$2.496{\pm}0.7^{a}$

Values are average of duplicate determination. CBE=cocoa butter equivalents (stearin: olein). 8= (62.5: 37.5) g and 9= (61.25: 38.75) g. Values with the same superscript showed no significant difference ($p > 0.05$).

CBE 9 with a value of 2.496±0.7 had the highest PV whilst CB with 1.489±0.7 had the least

PV. Statistically, there was no significant difference between the PV's of all the oils. The PV of the various oils were below the acceptable CODEX Standard limit of 10 meq O_2/kg oil (CODEX STAN, 2001).

Oil with low PV are of good quality and indicative of proper handling and preservation (exposure to high temperature, oxygen and light) of the oil whilst a high value is indicative of rancid oil. Nevertheless, an oil sample may record a low PV if oxidation is in the advanced stage (Miller, 2010).

4.1.4 Free Fatty Acid (FFA) value

This test was carried out to measure the free fatty acids present in cocoa butter and cocoa butter equivalents. FFA value is the percentage by weight of a specified fatty acid (Selinger, 2017). Presence of free fatty acid in oil will stimulate the oxidation of such oil sample.

According to CODEX STAN 86-1981, cocoa butter should not have an FFA value more than 1.75%m/m expressed as oleic acid.

Table 4.4: Free fatty acid values of cocoa butter and cocoa butter equivalents used in chocolate formulation

SAMPLE	FREE FATTY ACID VALUE (%)
Cocoa Butter	1.15 ± 0.04^{a}
CBE 8	1.64 ± 0.02^{b}
CBE 9	1.52 ± 0.08^{b}

FFA value is expressed as oleic acid. Values are average of duplicate determination. CBE=cocoa butter equivalents (stearin: olein). 8= (62.5: 37.5) g and 9= (61.25: 38.75) g. Values with the same superscript showed no significant difference ($p > 0.05$).

Amongst the three (3) oils analyzed, cocoa butter had the least FFA value of 1.15±0.04 whereas the oil with highest FFA value was CBE 8 with a value of 1.64±0.02. However, FFA values of all the oils were below the acceptable limits of 1.75% m/m. Oils with low FFA value are of good quality whereas high values are indicative of rancid oils.

The FFA value of both cocoa butter equivalents (CBE 8 and CBE 9) were significantly different from that of cocoa butter. This may be due to the different handling and preservation methods of the oils. The FFA value of CBE 8 was not significantly different from FFA value of CBE 9.

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4.1.5 Sensory Evaluation

4.1.5.1 Difference from Control Test

This test was employed to determine if there was a difference between the 2 chocolate samples made with cocoa butter equivalents (CBEs) and the control sample, which is chocolate made with cocoa butter only. Also, in this test, the subjects indicated the magnitude of the difference they perceived. This test assessed the overall difference among the chocolate samples. Table 4.5 shows the statistical analysis of the responses from the subjects involved in this test.

Table 4.5: Difference from control test performed by consumers

Sample	Mean and Standard deviation	Inference
CBE_8	3.33 ± 1.51^{b}	Slight difference
CBE_9	3.86 ± 1.50^{b}	Slight difference
Control	1.00 ± 0.00^{a}	No difference

Values with the same superscript showed no significant difference ($p > 0.05$). CBE=cocoa butter equivalents (stearin: olein). 8= (62.5: 37.5) g and 9= (61.25: 38.75) g. Values with the same superscript showed no significant difference ($p > 0.05$).

Refer to Appendix 6 for inference from scale.

The panellists observed a significant difference between the chocolate made with cocoa butter only and that made with cocoa butter equivalents. Notwithstanding, statistically, the subjects observed no significant difference between the chocolates made with cocoa butter equivalents 8 and 9. This may imply that the ratio of stearin and olein in the two cocoa butter equivalents had no significant effect on the consumer perception of chocolates made with the oils. Hence, prior to production, chocolate producer using cocoa butter equivalents 8 or 9 may consider other factors aside the stearin and olein ratios that may impair consumer perception.

4.1.5.2 Hedonic Rating Test

This test compared the subjects' preference of chocolate made with cocoa butter equivalents (shea stearin and palm olein at different ratios) as against that made with cocoa butter only.

Table 4.6: Hedonic ratings performed by consumers

Sample	Mean and Standard deviation	Inference
CBE_8	4.08 ± 2.089^{a}	Like slightly
CBE_9	3.67 ± 1.882^{a}	Like moderately
Control	3.47 ± 2.035^{a}	Like moderately

Values with the same superscript show no significant difference. CBE=cocoa butter equivalents (stearin: olein). 8= (62.5: 37.5) g and 9= (61.25: 38.75) g. Values with the same superscript showed no significant difference ($p > 0.05$). Refer to Appendix 7 for interpretation of inference from scale.

Inference from the 9-point Hedonic scale used in this evaluation indicated that the level of liking of the chocolate made with CBE 8 was different from that made with CBE 9 and CB (cocoa butter) only at a value of 4.08±2.089. Also, the level of liking of chocolates made with CB only was the same as that made with CBE 9.

However, there was no significant difference observed in the panel's acceptance of all three chocolates. This implies that at a 5% replacement of product base, cocoa butter equivalents could be used in chocolate making and such chocolate would have a comparable sensorial acceptance as chocolate made with cocoa butter only.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Cocoa butter equivalents from shea stearin and palm olein can be an alternative to cocoa butter at different ratios. It was observed that cocoa butter equivalents with palm olein and shea stearin ratio of 62.5%:37.5% (CBE 8) and 61.25%:38.75% (CBE 9) were not significantly different from cocoa butter used in this study.

From the sensorial analyses, there was a significant difference between consumer perception of chocolate made with the formulated CBE (with a 5% replacement on product base) and chocolate made with CB only. Nonetheless, there was no significant difference in subjects' preference of either chocolate made with CBE and that made with CB only.

5.2 RECOMMENDATION

Based on the results and conclusion, the following recommendations have been made:

1. A larger number of trained respondents (100 or more) could be used for the sensory analysis. Instrumental analysis could be conducted and compare the results with that of sensorial analysis.
2. Shelf life studies could be carried out on chocolate produced with 5% CBEs.
3. Further studies could be done on the fat crystals of the chocolate produced (chocolate with 5% CBE).
4. Production of cocoa butter equivalents (palm olein - shea stearin blend) could be adopted for commercial purposes.

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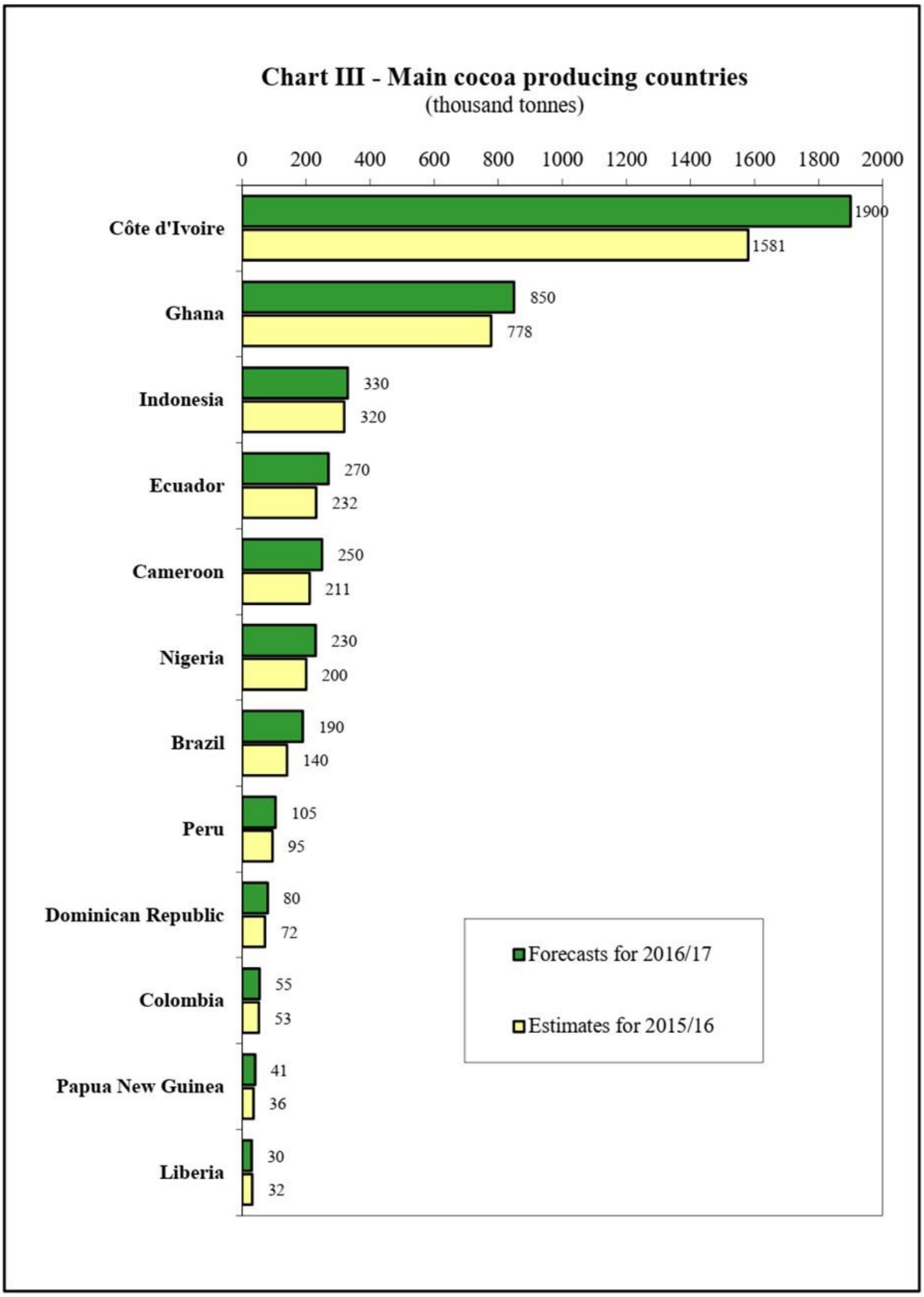
DOI 10.1007/978-3-319-24789-2_1. ISBN: 978-3-319-24787-8

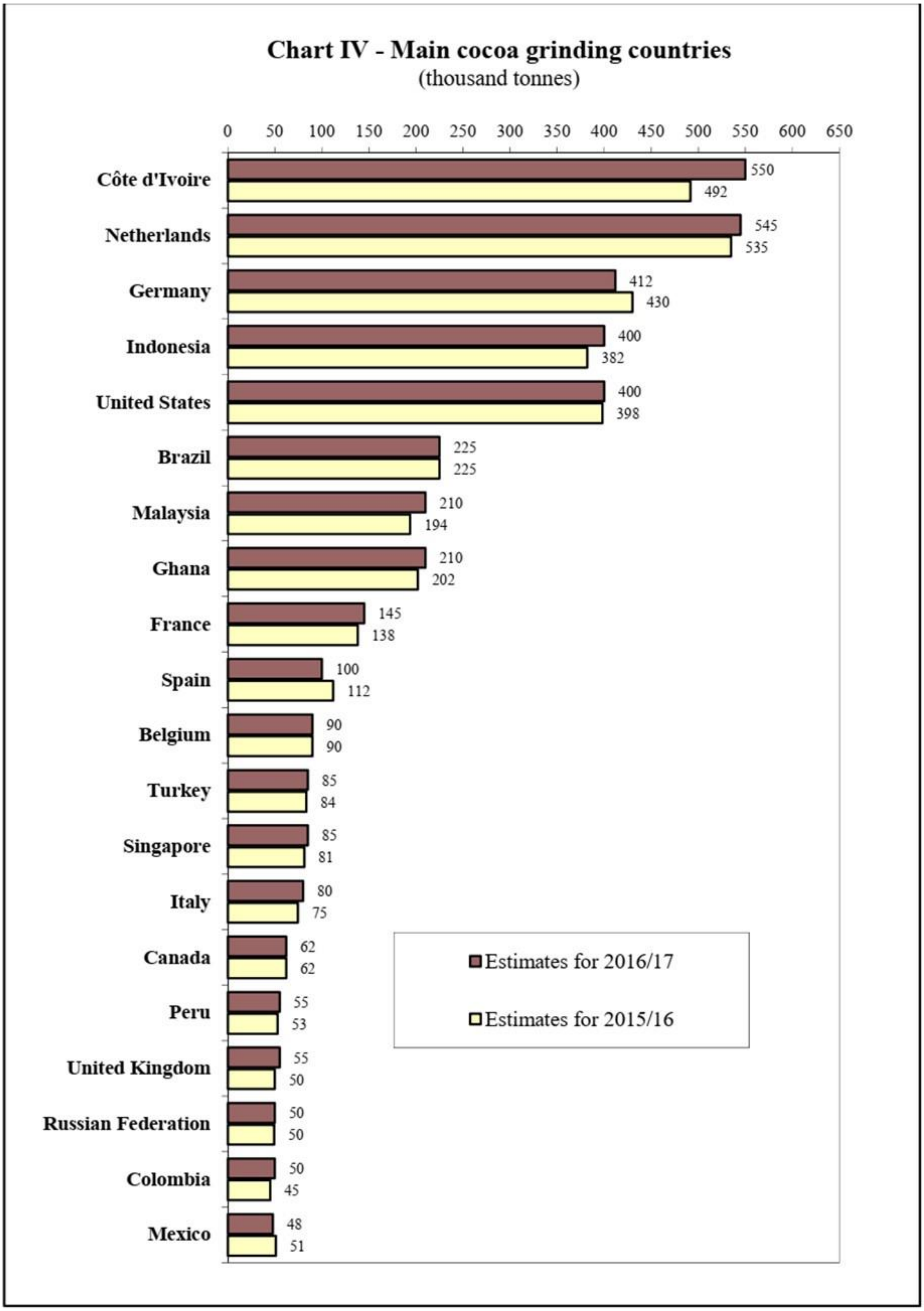
APPENDIX

APPENDIX 1: Cocoa Producing Countries



International Cocoa Organization
QBCS, Vol. XLIII No. 1, Cocoa year 2016/17

APPENDIX 2: Cocoa Grindings by Country



APPENDIX 3: RSM used for first composition

Std	Run	Component 1 A:Stearins %	Component 2 B:Oleans %	Response 1 R1
1	1	65	35	
2	2	60	40	
3	3	63.3333	36.6667	
4	4	61.6667	38.3333	
8	5	65	35	
9	6	60	40	
10	7	65	35	
7	8	62.5	37.5	
6	9	61.25	38.75	
5	10	63.75	36.25	

APPENDIX 4: Amount weighed expressed in grams (g)

S/N	**RSM FORMULATION (%)**		**AMOUNT WEIGHED (g) at 5%**	
	Stearin	Olein	Stearin	Olein
Run 1	65.0000	35.0000	3.2562	1.8112
Run 2	60.0000	40.0000	3.0064	2.0431
Run 3	63.3333	36.6667	3.1679	1.8774
Run 4	61.6667	38.3333	3.0858	1.9167
Run 5	65.0000	35.0000	3.2574	1.7521
Run 6	60.0000	40.0000	3.0019	2.0025
Run 7	65.0000	35.0000	3.2534	1.7619
Run 8	62.5000	37.5000	3.1312	1.8814
Run 9	61.2500	38.7500	3.0690	1.9504
Run 10	63.7500	36.2500	3.1984	1.8429

APPENDIX 5: RECRUITMENT SHEET

Taster no: …………..

Sex: Male / Female (underline status) Date:………………..….

Age range: ☐ 15-20 ☐ 21-26 ☐ 27-32 ☐ 33-39

1. Do you eat chocolates? Yes / No (indicate by *underlying*).

If you chose **no** for the question above, kindly draw the attention of the supervisor to this exercise.

2. Are you allergic to any of these ingredients? Tick where applicable

☐ Coco powder ☐ Cocoa butter

☐ Lecithin ☐ Sugar

☐ Milk powder ☐ Vanilla

3. Do you have difficulty detecting any taste? Yes/ No (indicate by *underlying*)
4. Have you had catarrh in the past week? Yes / No (*indicate by underlying*)
5. How often do you eat chocolates?

☐ Once a week ☐ on festive seasons (Easter, Christmas, Eid, birthday etc.)

☐ Once a month ☐ once every three months ☐ everyday

☐ Not regulated

6. Have you had chocolate in the last three (3) months? Yes / No

Appendix 6: SENSORY EVALUATION: DIFFERENCE FROM CONTROL TEST

Assessors Questionnaire

Product name: ……………………………. **Date: ………………..….**

Sex: Male / Female (underline status) **Age range (**tick that which pertains to you**):** ☐ **15-20** ☐ **21-26** ☐ **27-32** ☐ **33-39**

Please rinse your mouth thoroughly with the water provided before starting the tasting. Rinse again thoroughly before tasting a sample with a different code. Chew on the cracker inbetween samples.

You are presented with a control sample labelled R and three test samples with three-digits codes. Taste samples, first the control sample then, the test sample given.

Indicate the magnitude of difference between the two samples by ticking which phrase best describes your thoughts.

Code	
No difference	
Very slight difference	
Slight difference	
Moderate difference	
Recognisable difference	
Large difference	
Very large difference	

THANK YOU FOR PARTICIPATING

Appendix 7: SENSORY ACCEPTANCE TEST: HEDONIC RATING TEST

Assessors Questionnaire

Product name: …………………………….. **Date: ………………..….**

Sex: Male / Female (underline status) **Age range (**tick that which pertains to you**):** ☐ **15-20** ☐ **21-26** ☐ **27-32** ☐ **33-39**

Please rinse your mouth with the water provided before starting the tasting. Rinse again thoroughly before tasting a sample with a different code. Chew on the cracker in-between samples.

You are presented with three (3) samples of ……………….and are asked to indicate how much you like or dislike each sample. Taste the samples one at a time in the order presented (from your left to right) and tick the phrase that best describes your view of the sample.

921 **313** **278**

Write the sample code you assess on top of the column. There should no tie in like or dislike of any two products.

Code / Phrases			
Like Extremely			
Like Very Much			
Like Moderately			
Like Slightly			
Neither Like nor Dislike			
Dislike Slightly			
Dislike Moderately			
Dislike Very Much			
Dislike Extremely			

Will you purchase the sample you like should it be on sale? Yes / No

Specific gravity (Appendix 8 and 9)

Appendix 8

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
cocoabutter	2	50.907350	.0000707	.0000500
CBE1	2	50.961800	.0871156	.0616000
CBE2	2	50.902300	.0018385	.0013000
CBE3	2	50.911250	.0009192	.0006500
CBE4	2	50.937650	.0647003	.0457500
CBE5	2	50.993050	.1281985	.0906500
CBE6	2	50.911000	.0035355	.0025000
CBE7	2	50.952900	.0578413	.0409000
CBE8	2	50.905950	.0013435	.0009500
CBE9	2	50.907700	.0001414	.0001000
CBE10	2	50.949850	.0563564	.0398500

Appendix 9 One sample test for Specific gravity

One-Sample Test

	Test Value = 50.9074					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
	-1.000			-.0000500		
cocoabutter		1	.500		-.000685	.000585
	.883			.0544000		
	-3.923			-.0051000		
CBE1		1	.539		-.728302	.837102
	5.923			.0038500		
CBE2	.661	1	.159	.0302500	-.021618	.011418
	.945			.0856500		
CBE3		1	.106		-.004409	.012109
CBE4		1	.628		-.551059	.611559
CBE5		1	.518		-1.066167	1.237467
CBE6	1.440	1	.386	.0036000	-.028166	.035366
CBE7	1.112	1	.466	.0455000	-.474184	.565184
CBE8	-1.526	1	.369	-.0014500	-.013521	.010621
CBE9	3.000	1	.205	.0003000	-.000971	.001571
CBE10	1.065	1	.480	.0424500	-.463892	.548792

Refractive Index (Appendix 10 and 11)

Appendix 10

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Cocoa_butter	2	1.462150	.0000707	.0000500
cbe_1	2	1.464900	.0008485	.0006000
cbe_2	2	1.464250	.0000707	.0000500

cbe_3	2	1.464350	.0000707	.0000500
cbe_4	2	1.464250	.0002121	.0001500
cbe_5	2	1.464350	.0000707	.0000500
cbe_6	2	1.464350	.0000707	.0000500
cbe_7	2	1.464300	0E-7[a]	0E-7
cbe_8	2	1.463550	.0012021	.0008500
cbe_9	2	1.462900	.0002828	.0002000
cbe_10	2	1.464250	.0000707	.0000500

a. t cannot be computed because the standard deviation is 0.

Appendix 11

One-Sample Test

	Test Value = 1.4622					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Cocoa_butter	-1.000	1	.500	-.0000500	-.000685	.000585
cbe_1	4.500	1	.139	.0027000	-.004924	.010324
cbe_2	41.000	1	.016	.0020500	.001415	.002685
cbe_3	43.000	1	.015	.0021500	.001515	.002785
cbe_4	13.667	1	.046	.0020500	.000144	.003956
cbe_5	43.000	1	.015	.0021500	.001515	.002785
cbe_6	43.000	1	.015	.0021500	.001515	.002785
cbe_8	1.588	1	.358	.0013500	-.009450	.012150
cbe_9	3.500	1	.177	.0007000	-.001841	.003241
cbe_10	41.000	1	.016	.0020500	.001415	.002685

Appendix 12: One-way Anova

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Specific_gravity	Between Groups	.018	10	.002	.571	.807
	Within Groups	.035	11	.003		
	Total	.053	21			
Refractive_index	Between Groups	.000	10	.000	5.951	.003
	Within Groups	.000	11	.000		
	Total	.000	21			

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Ssample	(J) Ssample	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Specific_gravity	CBE1	CBE2	.0595000	.0562060	.987	-.163280	.282280
		CBE3	.0505500	.0562060	.996	-.172230	.273330
		CBE4	.0241500	.0562060	1.000	-.198630	.246930
		CBE5	-.0312500	.0562060	1.000	-.254030	.191530
		CBE6	.0508000	.0562060	.996	-.171980	.273580
		CBE7	.0089000	.0562060	1.000	-.213880	.231680
		CBE8	.0558500	.0562060	.991	-.166930	.278630
		CBE9	.0541000	.0562060	.993	-.168680	.276880
		CBE10	.0119500	.0562060	1.000	-.210830	.234730
		cocoabutter	.0544500	.0562060	.993	-.168330	.277230
	CBE2	CBE1	-.0595000	.0562060	.987	-.282280	.163280
		CBE3	-.0089500	.0562060	1.000	-.231730	.213830
		CBE4	-.0353500	.0562060	1.000	-.258130	.187430
		CBE5	-.0907500	.0562060	.848	-.313530	.132030
		CBE6	-.0087000	.0562060	1.000	-.231480	.214080
		CBE7	-.0506000	.0562060	.996	-.273380	.172180
		CBE8	-.0036500	.0562060	1.000	-.226430	.219130
		CBE9	-.0054000	.0562060	1.000	-.228180	.217380
		CBE10					
		cocoabutter					
	CBE3						

	CBE1	-.0475500	.0562060	.997	-.270330	.175230
	CBE2	-.0050500	.0562060	1.000	-.227830	.217730
	CBE4	-.0505500	.0562060	.996	-.273330	.172230
	CBE5	.0089500	.0562060	1.000	-.213830	.231730
	CBE6	-.0264000	.0562060	1.000	-.249180	.196380
	CBE7	-.0818000	.0562060	.908	-.304580	.140980
	CBE8	.0002500	.0562060	1.000	-.222530	.223030
	CBE9	-.0416500	.0562060	.999	-.264430	.181130
	CBE10	.0053000	.0562060	1.000	-.217480	.228080
	cocoabutter	.0035500	.0562060	1.000	-.219230	.226330
CBE4	CBE1	-.0386000	.0562060	1.000	-.261380	.184180
	CBE2	.0039000	.0562060	1.000	-.218880	.226680
	CBE3	-.0241500	.0562060	1.000	-.246930	.198630
	CBE5	.0353500	.0562060	1.000	-.187430	.258130
	CBE6	.0264000	.0562060	1.000	-.196380	.249180
	CBE7	-.0554000	.0562060	.992	-.278180	.167380
	CBE8	.0266500	.0562060	1.000	-.196130	.249430
	CBE9	-.0152500	.0562060	1.000	-.238030	.207530
	CBE10	.0317000	.0562060	1.000	-.191080	.254480
	cocoabutter	.0299500	.0562060	1.000	-.192830	.252730
CBE5	CBE1	-.0122000	.0562060	1.000	-.234980	.210580

.0562060

	CBE2	.0303000	.0562060	1.000	-.192480	.253080
	CBE3	.0312500	.0562060	1.000	-.191530	.254030
	CBE4	.0907500	.0562060	.848	-.132030	.313530
	CBE6	.0818000	.0562060	.908	-.140980	.304580
		.0554000	.0562060	.992	-.167380	.278180
		.0820500	.0562060	.906	-.140730	.304830
	CBE7	.0401500		.999	-.182630	.262930
	CBE8	.0871000	.0562060	.874	-.135680	.309880
	CBE9	.0853500	.0562060	.886	-.137430	.308130
	CBE10	.0432000	.0562060	.999	-.179580	.265980
	cocoabutter	.0857000	.0562060	.884	-.137080	.308480
CBE6	CBE1	-.0508000	.0562060	.996	-.273580	.171980
	CBE2	.0087000	.0562060	1.000	-.214080	.231480
	CBE3	-.0002500	.0562060	1.000	-.223030	.222530
	CBE4	-.0266500	.0562060	1.000	-.249430	.196130
	CBE5	-.0820500	.0562060	.906	-.304830	.140730
	CBE7	-.0419000	.0562060	.999	-.264680	.180880
	CBE8	.0050500	.0562060	1.000	-.217730	.227830
	CBE9	.0033000	.0562060	1.000	-.219480	.226080
	CBE10	-.0388500	.0562060	.999	-.261630	.183930
	cocoabutter					
CBE7	CBE1					

.0562060

	CBE2	.0036500	.0562060	1.000	-.219130	.226430
	CBE3	-.0089000	.0562060	1.000	-.231680	.213880
	CBE4	.0506000	.0562060	.996	-.172180	.273380
	CBE5	.0416500	.0562060	.999	-.181130	.264430
	CBE6	.0152500	.0562060	1.000	-.207530	.238030
	CBE8	-.0401500	.0562060	.999	-.262930	.182630
	CBE9	.0419000	.0562060	.999	-.180880	.264680
	CBE10	.0469500	.0562060	.998	-.175830	.269730
	cocoabutter	.0452000	.0562060	.998	-.177580	.267980
		.0030500	.0562060	1.000	-.219730	.225830
		.0455500	.0562060	.998	-.177230	.268330
CBE8	CBE1	-.0558500		.991	-.278630	.166930
CBE9	CBE2	.0036500	.0562060	1.000	-.219130	.226430
	CBE3	-.0053000	.0562060	1.000	-.228080	.217480
	CBE4	-.0317000	.0562060	1.000	-.254480	.191080
	CBE5	-.0871000	.0562060	.874	-.309880	.135680
	CBE6	-.0050500	.0562060	1.000	-.227830	.217730
	CBE7	-.0469500	.0562060	.998	-.269730	.175830
	CBE9	-.0017500	.0562060	1.000	-.224530	.221030
	CBE10					
CBE10	cocoabutter	-.0439000	.0562060	.999	-.266680	.178880
			.0562060			

CBE1	-.0014000	.0562060	1.000	-.224180	.221380
CBE2	-.0541000	.0562060	.993	-.276880	.168680
CBE3	.0054000	.0562060	1.000	-.217380	.228180
CBE4	-.0035500	.0562060	1.000	-.226330	.219230
CBE5	-.0299500	.0562060	1.000	-.252730	.192830
CBE6	-.0853500	.0562060	.886	-.308130	.137430
CBE7	-.0033000	.0562060	1.000	-.226080	.219480
CBE8	-.0452000	.0562060	.998	-.267980	.177580
CBE10	.0017500	.0562060	1.000	-.221030	.224530
cocoabutter	-.0421500	.0562060	.999	-.264930	.180630
CBE1	.0003500	.0562060	1.000	-.222430	.223130
CBE2	-.0119500	.0562060	1.000	-.234730	.210830
CBE3	.0475500	.0562060	.997	-.175230	.270330
CBE4	.0386000	.0562060	1.000	-.184180	.261380
CBE5	.0122000	.0562060	1.000	-.210580	.234980
	-.0432000	.0562060	.999	-.265980	.179580
CBE6	.0388500	.0562060	.999	-.183930	.261630

		CBE7	-.0030500	.0562060	1.000	-.225830	.219730
		CBE8					
			.0439000	.0562060	.999	-.178880	.266680
		CBE9					
		cocoabutter	.0421500	.0562060	.999	-.180630	.264930
		CBE1	.0425000	.0562060	.999	-.180280	.265280
		CBE2					
	cocoabutter	CBE3	-.0544500	.0562060	.993	-.277230	.168330
		CBE4	.0050500	.0562060	1.000	-.217730	.227830
		CBE5					
			-.0039000	.0562060	1.000	-.226680	.218880
		CBE6					
		CBE7	-.0303000	.0562060	1.000	-.253080	.192480
		CBE8					
			-.0857000	.0562060	.884	-.308480	.137080
		CBE9					
		CBE10	-.0036500	.0562060	1.000	-.226430	.219130
		CBE2					
			-.0455500	.0562060	.998	-.268330	.177230
		CBE3					
	CBE1	CBE4	.0014000	.0562060	1.000	-.221380	.224180
		CBE5					
			-.0003500	.0562060	1.000	-.223130	.222430
		CBE6					
		CBE7	-.0425000	.0562060	.999	-.265280	.180280
		CBE8	.0006500	.0004592	.920	-.001170	.002470
		CBE9	.0005500	.0004592	.970	-.001270	.002370
Refractive_index	CBE2						

KNUST

CBE10	.0006500	.0004592	.920	-.001170	.002470
cocoabutter	.0005500	.0004592	.970	-.001270	.002370
CBE1	.0005500	.0004592	.970	-.001270	.002370
	.0006000	.0004592	.949	-.001220	.002420
	.0013500	.0004592	.223	-.000470	.003170
	.0020000*	.0004592	.028	.000180	.003820
	.0006500	.0004592	.920	-.001170	.002470
	.0027500*	.0004592	.003	.000930	.004570
	-.0006500	.0004592	.920	-.002470	.001170

-.0001000	.0004592	1.000	-.001920	.001720
0E-7	.0004592	1.000	-.001820	.001820
-.0001000	.0004592	1.000	-.001920	.001720
-.0001000	.0004592	1.000	-.001920	.001720
-.0000500	.0004592	1.000	-.001870	.001770
.0007000	.0004592	.884	-.001120	.002520
.0013500	.0004592	.223	-.000470	.003170
0E-7	.0004592	1.000	-.001820	.001820
.0021000*	.0004592	.020	.000280	.003920
-.0005500	.0004592	.970	-.002370	.001270
.0001000	.0004592	1.000	-.001720	.001920
.0001000	.0004592	1.000	-.001720	.001920
0E-7	.0004592	1.000	-.001820	.001820
0E-7	.0004592	1.000	-.001820	.001820
.0000500	.0004592	1.000	-.001770	.001870
.0008000	.0004592	.790	-.001020	.002620

KNUST
NYANSAPƆ WƆSANE NO BADWENMA

CBE3

CBE4

CBE5

CBE6

CBE7

CBE8

CBE9 CBE10

cocoabutter

CBE1

CBE2

CBE4

CBE5

CBE6

.0014500	.0004592	.165	-.000370	.003270
.0001000	.0004592	1.000	-.001720	.001920
.0022000*	.0004592	.014	.000380	.004020
-.0006500	.0004592	.920	-.002470	.001170
0E-7	.0004592	1.000	-.001820	.001820
-.0001000	.0004592	1.000	-.001920	.001720
-.0001000	.0004592	1.000	-.001920	.001720
-.0001000	.0004592	1.000	-.001920	.001720
-.0000500	.0004592	1.000	-.001870	.001770

CBE3

CBE7

CBE8

CBE9 CBE10

cocoabutter

CBE1

CBE2

CBE3

CBE4

CBE5

CBE6

CBE7

.0007000	.0004592	.884	-.001120	.002520
.0013500	.0004592	.223	-.000470	.003170
0E-7	.0004592	1.000	-.001820	.001820
.0021000*	.0004592	.020	.000280	.003920
-.0005500	.0004592	.970	-.002370	.001270
.0001000	.0004592	1.000	-.001720	.001920
0E-7	.0004592	1.000	-.001820	.001820
.0001000	.0004592	1.000	-.001720	.001920
0E-7	.0004592	1.000	-.001820	.001820
.0000500	.0004592	1.000	-.001770	.001870
.0008000	.0004592	.790	-.001020	.002620
.0014500	.0004592	.165	-.000370	.003270
.0001000	.0004592	1.000	-.001720	.001920
.0022000*	.0004592	.014	.000380	.004020
-.0005500	.0004592	.970	-.002370	.001270
.0001000	.0004592	1.000	-.001720	.001920

	CBE8					
	CBE9 CBE10	0E-7	.0004592	1.000	-.001820	.001820
	cocoabutter	.0001000	.0004592	1.000	-.001720	.001920
	CBE1					
	CBE2	0E-7	.0004592	1.000	-.001820	.001820
	CBE3	.0000500	.0004592	1.000	-.001770	.001870
	CBE4	.0008000	.0004592	.790	-.001020	.002620
	CBE6					
CBE5	CBE7	.0014500	.0004592	.165	-.000370	.003270
	CBE8	.0001000	.0004592	1.000	-.001720	.001920
	CBE9 CBE10					
	cocoabutter	.0022000*	.0004592	.014	.000380	.004020
	CBE1	-.0006000	.0004592	.949	-.002420	.001220
	CBE2					

CBE3
CBE4
CBE5
CBE7
CBE8

CBE6
CBE9 CBE10
cocoabutter
CBE7 CBE1

.0000500	.0004592	1.000	-.001770	.001870
-.0000500	.0004592	1.000	-.001870	.001770
.0000500	.0004592	1.000	-.001770	.001870
-.0000500	.0004592	1.000	-.001870	.001770
-.0000500	.0004592	1.000	-.001870	.001770
.0007500	.0004592	.840	-.001070	.002570
.0014000	.0004592	.192	-.000420	.003220
.0000500	.0004592	1.000	-.001770	.001870
.0021500*	.0004592	.017	.000330	.003970
-.0013500	.0004592	.223	-.003170	.000470
-.0007000	.0004592	.884	-.002520	.001120
-.0008000	.0004592	.790	-.002620	.001020
-.0007000	.0004592	.884	-.002520	.001120
-.0008000	.0004592	.790	-.002620	.001020
-.0008000	.0004592	.790	-.002620	.001020
-.0007500	.0004592	.840	-.002570	.001070

KNUST

CBE2
CBE3
CBE4
CBE5
CBE6
CBE8
CBE9 CBE10
cocoabutter
CBE1
CBE2
CBE3
CBE4
CBE5
CBE8

	.0006500	.0004592	.920	-.001170	.002470
	-.0007000	.0004592	.884	-.002520	.001120
	.0014000	.0004592	.192	-.000420	.003220
	-.0020000*	.0004592	.028	-.003820	-.000180
	-.0013500	.0004592	.223	-.003170	.000470
	-.0014500	.0004592	.165	-.003270	.000370
	-.0013500	.0004592	.223	-.003170	.000470
	-.0014500	.0004592	.165	-.003270	.000370
	-.0014500	.0004592	.165	-.003270	.000370

CBE6
CBE7
CBE9 CBE10
cocoabutter
CBE1
CBE2
CBE3
CBE9
CBE4
CBE5
CBE6

NYANSAPO WO SANE NO BADWENMA

	CBE7	-.0014000	.0004592	.192	-.003220	.000420
	CBE8					
	CBE10	-.0006500	.0004592	.920	-.002470	.001170
	cocoabutter	-.0013500	.0004592	.223	-.003170	.000470
	CBE1					
	CBE2	.0007500	.0004592	.840	-.001070	.002570
	CBE3	-.0006500	.0004592	.920	-.002470	.001170
	CBE4					
CBE10	CBE5	0E-7	.0004592	1.000	-.001820	.001820
	CBE6	-.0001000	.0004592	1.000	-.001920	.001720
	CBE7					
	CBE8	0E-7	.0004592	1.000	-.001820	.001820
	CBE9	-.0001000	.0004592	1.000	-.001920	.001720
	cocoabutter					
	CBE1	-.0001000	.0004592	1.000	-.001920	.001720
	CBE2	-.0000500	.0004592	1.000	-.001870	.001770
	CBE3					
	CBE4	.0007000	.0004592	.884	-.001120	.002520
cocoabutter	CBE5	.0013500	.0004592	.223	-.000470	.003170
	CBE6					
	CBE7	.0021000*	.0004592	.020	.000280	.003920
	CBE8	-.0027500*	.0004592	.003	-.004570	-.000930
	CBE9	-.0021000*	.0004592	.020	-.003920	-.000280

CBE10	-.0022000*	.0004592	.014	-.004020	-.000380
	-.0021000*	.0004592	.020	-.003920	-.000280
	-.0022000*	.0004592	.014	-.004020	-.000380
	-.0022000*	.0004592	.014	-.004020	-.000380
	-.0021500*	.0004592	.017	-.003970	-.000330
	-.0014000	.0004592	.192	-.003220	.000420
	-.0007500	.0004592	.840	-.002570	.001070
	-.0021000*	.0004592	.020	-.003920	-.000280

*. The mean difference is significant at the 0.05 level.

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ANOVA

PV

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.345	2	.672	1.359	.380
Within Groups	1.484	3	.495		
Total	2.829	5			

ANOVA

FFA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.263	2	.131	43.484	.006
Within Groups	.009	3	.003		
Total	.272	5			

Multiple Comparisons

Dependent Variable: FFA

Tukey HSD

(I) OILS	(J) OILS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
CB	cbe_8	-.4934500*	.0549406	.006	-.723031	-.263869
	cbe_9	-.3661500*	.0549406	.014	-.595731	-.136569
cbe_8	CB	.4934500*	.0549406	.006	.263869	.723031
	cbe_9	.1273000	.0549406	.196	-.102281	.356881
cbe_9	CB	.3661500*	.0549406	.014	.136569	.595731
	cbe_8	-.1273000	.0549406	.196	-.356881	.102281

*. The mean difference is significant at the 0.05 level.

Figure 1: Stearin weighed into container

Figure 2: Olein weighed unto Stearin in container

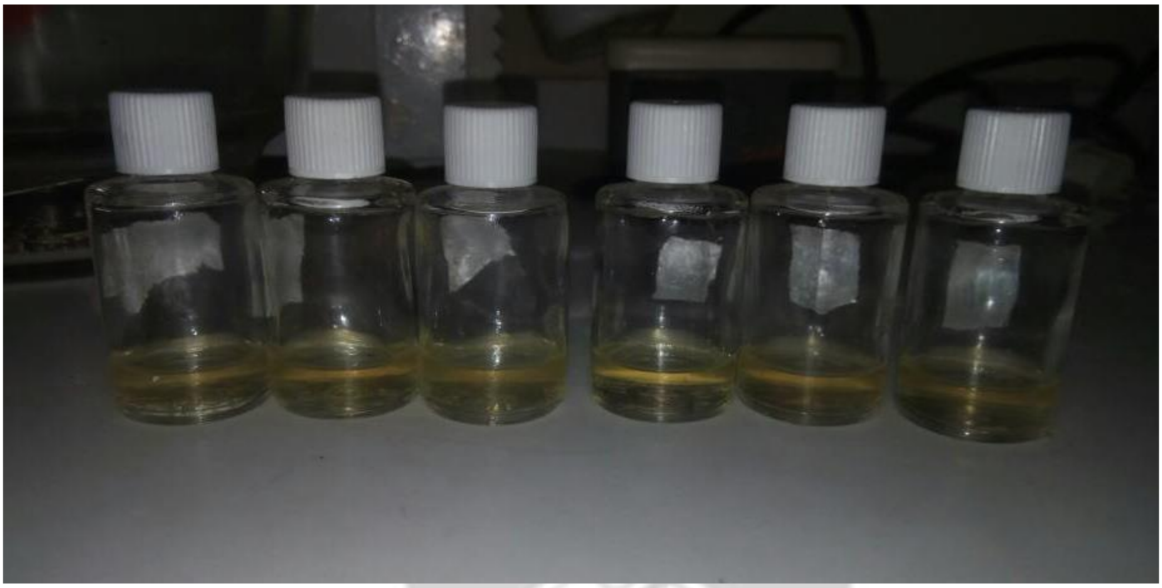

Figure 3: Mixture after being placed in water bath at 65°C for 5minutes

Figure 4: Mixture after storing over night at ambient temperature

Figure 5: Melted pure cocoa butter